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THE GEOLOGY OF
THE BRITISH EMPIRE

THE GEOLOGY
OF
THE BRITISH EMPIRE

BY
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SECOND EDITION

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PREFACE TO SECOND EDITION

Since the publication of the first edition of this book in 1921 the investigation of the geology of nearly every part of the British Empire has been carried on by a host of workers and has resulted in a great increase of our knowledge. The revision of many of the chapters has thus been necessary. Moreover, by visits to India, Burma, Ceylon, South Africa, Canada, Cyprus, Jamaica, Palestine and other places, the author has acquired a personal acquaintance with much of the geology of these countries. A re-arrangement of much of the matter and considerable additions to the list of references has been deemed desirable, so as to widen its usefulness to other than University students, and to help those engaged in economic, paleontological and petrological research. Certain areas under British protection or influence are included in this edition on account of their geological interest.

January, 1946.

F. R. C. R.

NOTE

This edition was the last work of Dr. Cowper Reed, who succeeded in completing it only a few weeks before he died. In compliance with his wish, I undertook to see the manual through the Press. In doing so, I have made no attempt to bring the text immediately up to date, but have left it almost exactly as it came from the author's pen. The only changes I have ventured to effect are : a slight re-adjustment of the chapters and headings ; the amendment of a statement concerning the Kalaw Red Beds of Burma, Dr. Reed having overlooked a published correction regarding the supposed ammonites found in these beds ; and negligible corrections which the author would himself have made had he corrected the proofs. It will be noticed that several of the numbered references have no corresponding note sign in the text; in most cases it has been thought best to ignore the omission of these note signs rather than attempt to guess where the author would have thought fit to insert them.

Miss P. L. Robinson has been kind enough to undertake the preparation of the index.

December, 1947.

EDWIN H. PASCOE,
Fallows Green," Harpenden.

PREFACE TO FIRST EDITION

Apart from certain standard works on the geology of India, South Africa, New Zealand, and a few other countries, much of our knowledge of the geology of the various distant parts of the British Empire is scattered through the pages of scientific journals and Government memoirs, or is found in foreign publications, most of which are difficult of access for the ordinary student, or too technical in character for the general reader. It was accordingly suggested to the present author that it would be of use to publish his notes for the course of lectures which he has given to Cambridge students during the last twelve years. It is obvious that such a vast field as is comprised within the British Empire can be only covered in an incomplete manner in a work of this kind, and the difficulty is increased in many cases by the meagre or unsatisfactory nature of our present knowledge of the different areas. The same method of treatment cannot therefore be always followed, nor can the same amount of detail be given.

It has been considered needless to incorporate any description of the geology of the British Isles themselves, as numerous excellent works on the subject are readily available.

The various political or geographical regions and countries are treated in such a manner in the following pages that each is as far as possible complete in itself, though this necessarily involves some repetition.

To a large extent it is unavoidable that a work of this nature and compass must be a compilation from so many sources that all cannot be acknowledged or quoted. A selection of references to the literature on the geology of each area has accordingly been made. The author is much indebted to the Director of the Geological Survey of India, the Director of the Geological Survey of Canada, and the Minister of Mines and Industries of the Union of South Africa, for kind permission to use the publications of their departments in the preparation of his generalised maps and sections, and to Mr. T. H. D. LaTouche for the map of Burma.

F. R. C. R.

January, 1921.

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CHAPTER I

THE MEDITERRANEAN AREA

SECTION I.—GIBRALTAR

Physical Features.—The promontory of Gibraltar forms a detached rocky ridge stretching from north to south for a length of three miles, with an average width of about three-quarters of a mile. The eastern face is precipitous, but on the west side the ground slopes down to the water more gradually in agreement with the general dip of the beds which compose it. At the north end the Rock rises abruptly above the low sandy plain connecting it with the mainland to a height of about 1350 ft., and thence the ridge runs as a sharp arete towards the south at an elevation of 1200 to 1400 ft., ending suddenly with a drop to the well-marked plateaus of Wind-mill Hill and Europa Flats and 120 ft. The former connection of Europe with the coast of Africa at this point is suggested by the fact that the shallowest part of the sea occurs at the narrowest place in the Straits between Tarifa and Alcazar Point ($9\frac{1}{4}$ miles distant), where it only attains a depth of 180-200 fathoms, but east and west of this line the sea-floor rapidly sinks till it reaches a depth of over 1000 fathoms between Gibraltar and Ceuta.

Geological Structure¹.—The solid rock consists principally of beds of limestone dipping to the west generally at high angles and with a strike coinciding mainly with the length of the promontory, but towards the north the strike bends more and more to the north east. According to the general dip of the beds, the strata become steeper towards the base of the rock, suggesting a reversed fold. For the most part the limestones are overlain by shales with intercalated beds of calcareous grit and hardened mudstones. On Windmill Hill and Europa Flats there is a remarkable reversal of inclination, for all the strata dip to the east at angles from 25° to 65°, or are in places vertical. This change of inclination occurs south of a main fault which cuts obliquely across the promontory at the south end of the principal ridge in a N.W.-S.E. direction. South of this fault the limestones seem to overlie the shales, but this apparent inversion of the order of succession indicates that the structure of the rock is not so simple as it at first appears, and that the beds have suffered considerable disturbance since their deposition.

Faults affecting an overturned fold which involves the limestones and shales will explain the inversion, if it can be established that the shales overlying the limestones are of the same geological age as those underlying them ; but palaeontological evidence on this point is at present unfortunately absent. Whether the limestones form the core of a reversed syncline or the crest of an anticline, in either case with the axis steeply inclined to the west, cannot be decided from the available facts, but the section given by Ramsay and Geikie of Windmill Hill Flats suggests a syncline.

In addition to the above-mentioned main fault there are two minor faults meeting it nearly at right angles on its north side, and trending N.N.E.-S.S.W. Probably another transverse fault cuts off the whole promontory from the sandy isthmus which connects it with the mainland so as to form the north face.

The solid rocks are more or less covered with superficial deposits (limestone-breccias, sands, etc.) of a much later date, and ossiferous breccias occur in caves and fissures. Wetzel¹⁸ describes in detail the petrology of some of the rocks, particularly of the limestone-breccias, on both sides of the Straits.

DETAILED DESCRIPTIONS OF THE GEOLOGICAL FORMATIONS AND THEIR RELATIONS

(1) The limestones which occupy more than three-quarters of the promontory are regularly bedded and of a greyish-white to pale-grey colour and of a compact or sometimes crystalline nature. The beds vary from 5 ft. to many yards in thickness. In places they are brecciated. Cherty bands are occasionally intercalated. With regard to their age, Hochstetter²³ mentions the presence in them of fossils comprising gastropods, the lamellibranch genus *Avicula*, and brachiopods (*Spirifer*, *Terebratula*, and *Rhynchonella*). In the British Museum there are a few fossils from Catalan Bay, Gibraltar, which have been identified as *Hemiptychina* sp. and are supposed to be of Carboniferous or Permian age, but no confirmation of the occurrence of rocks of this age is available. According to De Verneuil's collection of fragmentary Ammonites and Rhynchonellas the beds belong to the Lias, but Davidson identified a brachiopod amongst them as *Rhynchonella concinna* of Cornbrash or Coral Rag age, though Kilian⁴ subsequently disputed the accuracy of this determination. Fossils are extremely rare, but in view of the evidence so far available it is probable the limestones belong to more than one stage of the Jurassic System.

The series of shales which occurs above the limestones north of the main fault consists of greyish-blue argillaceous beds weathering to various colours. Intercalated amongst them are grits, mudstones, and thin limestones, especially in their lower part. These seem to belong to the Flysch (Cretaceous) which is largely developed westwards towards Tarifa and inland. No fossils have as yet been recorded from them.

Light is, however, thrown on the age of all these beds by considering the geological relations of Gibraltar with the neighbouring lands. For the promontory of Gibraltar is intimately connected in its geological history⁵ with

the whole western end of the Mediterranean, as it lies on the track of **the** Alpine folds which encircle this portion of the sea, and link together the North African and Spanish systems. From Tunis to Ceuta the North African coast is formed of ancient crystalline and Palaeozoic rocks bordered by an interrupted marginal zone of comparatively recent volcanic outbursts. South of the ancient rocks come Permian or Carboniferous beds overlaid by masses of limestones belonging to the Triassic, Jurassic, Cretaceous and Eocene, all of which are very much folded, the folds striking with the mountain chain which runs W.S.W. from Tunis into Morocco, where in the Riff region it bends northward to meet the coast at the Straits of Gibraltar. Here the mountain of Abyla consists of limestone overlain and underlain by shales and sandstones with the same strike and characters as those of Gibraltar and of the adjacent regions in Spain. For, on the west side of Gibraltar Bay, the coast of Spain exhibits sandstones and shales which dip generally to the west or north-west, apparently overlying beds of limestone. These are probably referable partly to the Cretaceous, but mostly to the Eocene. All are considerably disturbed and contorted. The south-east coastal region of Spain repeats the structure and succession of beds which have been described between Tunis and Ceuta, so that along the south side of the great central Spanish *meseta* runs a series of chains forming the Betic Cordillera, from W.S.W. to E.N.E., the innermost chain or northern zone being composed of Mesozoic limestones and Eocene deposits overlying the more ancient rocks and thrown into a great series of folds which possess the same north-easterly strike, and are traversed by parallel longitudinal strike-faults. The folds are ultimately traceable with a curved strike into the Balearic Isles. This system of folds surrounds a great sunken region, now occupied by the west end of the Mediterranean, and structurally resembles the borders of the Hungarian plain. The date of the formation of these folds is Miocene, and they constitute part of the great Alpine Orogenic System. The North African chain appears to have been formed by a movement directed to the south or south-east, while the Betic Cordillera, which is connected with it across the Straits of Gibraltar, was produced by a force acting in a north or north-westerly direction against the foreland represented by the Sierra Morena, the pressure having been directed outwards in each direction from the foundered area of the western Mediterranean. Termier and Jessen¹⁵ dispute Suess' theory of the structure and relation of the beds on opposite sides of the Straits, but their arguments are not conclusive, and Kober¹⁷ maintains the correspondence of the strata and of the structure on both sides of the Straits, and contends that the Mesozoic limestones have been thrust over the Flysch. Others have pointed out that there is evidence of two periods of folding resulting in two sets of folds with different orientation, the Tertiary beds being affected by folds running E.N.E. to W.S.W., while the older beds have a meridional strike. Blumenthal²² recognises a series of 'Antibetic' folds in the Cretaceous and Jurassic beds occurring to the west of Algeciras and forming part of those in the Gibraltar arc; these folds have their convexity to the east, and owe their origin to pressure from the west. The formation of the Straits themselves is probably due to a transverse fault dating from the Pliocene,²¹ but there was apparently a later temporary land-bridge formed before the final separation of Europe from North Africa.

(2) **Superficial Deposits**¹⁷.—The oldest superficial deposit is termed the 'Older Limestone Agglomerate,' and rests directly on the solid rock of the peninsula. It consists¹⁸ of angular fragments and blocks of limestone up to 20 or 30 tons in weight heaped together in confusion and **imbedded in a greyish or reddish matrix of calcified grit and earth rarely showing any signs of**

stratification. The deposit varies in thickness from a few feet up to 100 ft. or more, being thinnest on the steeper slopes, where it tends to occur in disconnected patches, but it becomes thicker towards the base of the rock. It is much weathered and seamed by gullies and ravines cut to a depth of 30-50 ft. Terraces and platforms have also been cut in it at various levels by marine action, and in places caves have been excavated which contain bone-deposits, etc. These features point to a considerable antiquity, and the character of the breccia indicates that it was formed when a much colder climate existed in this region, and severe frosts split off blocks of the solid rocks forming extensive screes, and avalanches of snow and 'earth-glaciers' spread the materials over the lower grounds. The slow downward movements of the sheets of earthy debris, rock-fragments, and soil by the seasonal freezing and thawing of the materials is a characteristic phenomenon of regions of high altitude (*e.g.* Tibet

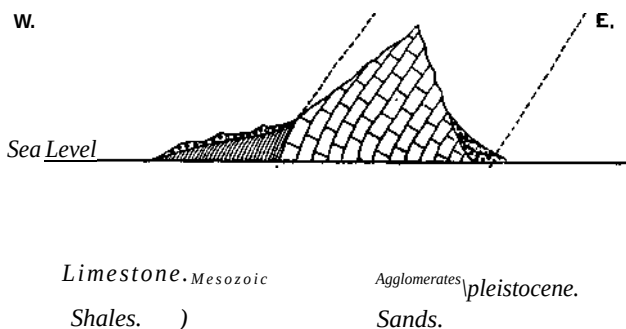


FIG. 1.—DIAGRAMMATIC SECTION ACROSS THE ROCK OF GIBRALTAR (based on Sections by Ramsay and Geikie), SUGGESTING A REVERSED FOLD.

and the Rocky Mountains), or of cold climates, and such 'solifluction' is strikingly illustrated by the 'flowing-soils' of arctic regions, such as the 'Stone Rivers' of the Falkland Islands. The theory put forward by Prestwich⁶ that this rubble-drift was formed by flood-action during a rapid upheaval after submergence does not seem to meet the facts of the case, and it is of the same nature as sub-aerial screes. The date of formation of this solidified rock-rubble on Gibraltar is regarded as coinciding with an early stage in the Pleistocene Glacial Period of Northern Europe when conditions of considerable climatic cold prevailed even in the Mediterranean area. To this stage Prof. James Geikie⁷ has given the name of the Saxonian or Second Glacial Epoch (=Mindelian of the Alps)—the epoch of maximum glaciation, and its effects on the solid rocks which were accompanied by the production of superficial accumulations similar to those on Gibraltar are observable throughout the south of Europe*. The characters of the associated fauna likewise point everywhere to severe cold.

Subsequent to the formation of the 'Older Limestone Agglomerate' milder

climatic conditions appear to have prevailed, and the deposit suffered considerable denudation. During this stage, which Geikie regards as corresponding to an interglacial epoch (the Tyrolian, or second interglacial epoch), a rich fauna existed in these parts, remains of which are now found in the caves and fissures of the Rock. Its character suggests a land-connection with the opposite African coast. The action of underground waters and the flow of torrents on the surface at this time excavated gullies and caverns in the soluble limestone and in the older breccias, and into these hollows were swept the carcasses of the mammalia and other vertebrates. Amongst these caves, the Genista cave has yielded a rich fauna⁹. Vast numbers of ibex and wild boar are represented in these deposits; and the bones of *Rhinoceros leptorhinus*, *Elephas meridionalis*, leopard (*Felis leopardus*), spotted hyaena (*Hyæna crocuta*), lion, southern lynx, bear, wolf, horse, deer, etc., have also been found in these ossiferous breccias^{8 9 10 13 19}. This abundant and varied assemblage of animals points to the existence of a rich vegetation and genial climate, and has predominant African affinities, the Felidæ at any rate, according to Falconer⁸, proving a land-connection with Africa. But some of the cave-deposits probably belong to a later date. Land shells of Pleistocene age also occur in the deposits²⁰.

The next succeeding deposits on the Rock are of a marine nature, and point to a considerable submergence of the land to at least the depth of 700 ft., which was succeeded by re-elevation. But the movement was not continuous or uninterrupted, and during the pauses the sea cut platforms and shelves in the bedded limestone or agglomerate, and spread masses of shelly sand and gravel on these terraces and on the slopes between them. Of the Raised beaches and rock-cut platforms thus formed five or six main ones may be distinguished. The lowest is found on Europa Point and on the New Mole Parade¹, where it is cut into the Older Limestone Agglomerate at a height of about 60 ft. above sea-level, and it contains shells of marine mollusca still living in the Mediterranean. The next is at a height of 70-75 ft. above sea-level, and likewise contains Recent marine mollusca. It is similarly cut into the Older Agglomerate, and occurs in the same neighbourhood as the lower beach. The Europa platform, forming the Europa Flats at a height of 120 ft., is regarded as the third terrace, and it is covered partly with the 'Newer Limestone Agglomerate,' and partly with a calcareous sandstone formed of indurated shelly sands. The succeeding platform is at a height of 250-260 ft., and is covered with a similar calcareous sandstone. The Windmill Hill Flats constitute the next level, forming a plateau at a height of 370 ft., and finally an elevated beach composed of recent marine deposits is stated to occur at a height of 700 ft. Probably the so-called *Alameda Sands* on which the greater part of the town of Gibraltar is built were laid down during one of these periods of submergence, though they have suffered rearrangement and induration. They are of a red siliceous character, and reach up to a height of 160-170 ft. On the eastern side of the promontory the sands of the groat talus stretching down from the cliffs from a height of 700 ft. to Catalan Bay, and known as the *Catalan Sands*, are scarcely consolidated and only partially cemented: they are probably of marine origin, though in part they have been subsequently washed down and spread out by rain and wind.

After the formation of these deposits and the re-elevation of the Rock cold climatic conditions again supervened, as the accumulation of the so-called *Newer Limestone Agglomerate' proves. This is of the same nature and origin as the Older Agglomerate and, according to Prof. J. Geikie⁷, was formed during the third or Polonian (=Rissian) Glacial Epoch. It is of the nature of screes and surface-soil which, under the influence of alternating frosts and thaws by day and night or of seasonal changes, slipped down the slopes and

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spread over the earlier deposits, the larger blocks occasionally sinking into the unconsolidated sands of the preceding interglacial stage. But the cold was of less intensity and less duration than that of the Second Glacial Epoch, though it has left its mark in most extra-glacial parts of Southern Europe.

The famous Forbes Quarry human skull¹⁴, which is of the Neanderthal type, has been supposed by Dr. Sera to indicate glacial conditions by its platycephalic characters, but its precise age is doubtful, and its mode of occurrence is also uncertain. It is believed to have come from a terrace formation of talus (? Newer Agglomerate) which accumulated when the climate was colder than at the present day. Recently another skull of the Neanderthal type has been found associated with Mousterian stone-implements¹⁶.

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SECTION II.—THE MALTESE ISLANDS

Physical Characteristics and Relations.—The islands of Malta and Gozo, with the small islet of Comino lying between them, are situated near the centre of the Mediterranean about 60 miles south of Sicily and 200 miles from the African coast, on one of the submarine banks connecting Africa⁵ with Europe. These banks, which here divide the Mediterranean into two main hydrographic basins reaching over 2000 fathoms in depth, represent parts of the submerged land-bridges of comparatively recent geological age, and are the fragments of a sunken land-area which was broken up in post-Miocene times. The Maltese Islands are placed at the southern end of one extensive bank which lies at an average depth of less than 50 fathoms and stretches from the south-east corner of Sicily in a southerly direction, being continued to Tripoli by the Medina Bank, and by a more deeply submerged portion; but the depths of the sea over it in no place exceed 300 fathoms, and an elevation of the sea-floor of a little over 50 fathoms would again unite Malta with Sicily. The western end of Sicily is connected with Tunis by another series of banks and shoals nowhere more than 200 fathoms below the surface of the water, and the volcanic islands are confined to this region. Between this submarine ridge and that carrying the Maltese Islands is a small basin with a depth of about 600 fathoms.

The main axis of the Maltese group of islands has a trend from north-west to south-east, and is about 29 miles in length, of which Malta occupies about 17 miles, and Gozo about 9 miles. Probably parallel fault-lines determine this trend, so that the islands may be regarded as 'horsts,' or the fragments of an elongated fault-block, which has been further broken up by more than one set of transverse fractures²¹.

The general topography of the islands is characterised by flat-topped hills, none rising to a greater height than 750 ft. In Malta the general surface of the ground slopes down gradually to the north in accordance with the prevalent dip of the strata, the cliffs on the southern and western sides rising to a height of 300-400 ft., while the northern shore is comparatively low and shelving, though at Valetta and St. Paul's Bay some high cliffs are found. A general description of the whole group of islands has been given by De Stefani²⁵.

Geological Structure^{1 la lb 2 3 8}.—The rocks of which the islands are composed consist of a series of Tertiary sediments, chiefly

of a calcareous nature, and frequently massive or crystalline ; but there are also some greensands, marls, and clays. Superficial deposits, especially limestone-breccias, fluvial loams, sands, and gravels, are found in the valleys, and the ossiferous breccias in the caves are famous.

The succession of the beds is as follows :—

Pleistocene Valley-deposits, cave-earths, limestone-breccias, etc.

{ Upper Coralline Limestone
 { Greensands
 { Clays and Marls

Upper division.

{ Globigerina Limestones

[Lower division.

Lower Coralline Limestone

All the beds vary much in thickness from place to place, but the total maximum is not much more than 1000 ft. They have mostly a very slight dip to the E.N.E. or N.E., or lie nearly horizontal without any marked disturbance. They are not folded to any important extent, but are traversed by two main sets of faults²⁸, the principal set of which is at right angles to the axis of the islands. Of this set the chief one in Malta crosses the island from Madalena Bay on the north-east coast to Fomm el Rieh on the opposite coast, and is marked by a series of steep cliffs. It is well shown near the west end of the Gianhina Valley on the south coast. The downthrow is to the north-west, being about 350 ft. at Fomm el Rieh, and 270 ft. at the other end. A parallel fault runs across the south-eastern end of Gozo, and drops the strata on the south-east, so that between these two main transverse faults a sunken mass of strata is found ; minor parallel trough-subsidences lie between them. The second group of faults makes a large angle with the first. The chief one of them occurs close to the south coast of Malta, and is known as the Malak fault; it has a throw of 350 ft., increasing to 550 ft. by the entrance of a second subordinate fault. Faulting continued into Pleistocene times, as shown by the effects on the Quaternary conglomerates²³. The circular depression known as the Marluba, which has been interpreted as due to a circular fault, seems to be of the nature of a true pot-hole, like those in the Carboniferous limestone of Yorkshire, and resembles the *dolinas* of Istria, originating from the collapse of the roof of a chamber in an underground watercourse.

Malta and Gozo are in fact the remains of a broken and sunken plateau of Tertiary rocks situated between the two great foundered eastern and western areas of the Mediterranean. They have not been involved in the Alpine system of folds which crosses the Medi-

terranean from Sicily to Tunis along the line of the western series of submarine banks in this region, but, on the other hand, belong tectonically to the sunken northern 'foreland' of the Indo-African continent which has been dropped in horizontal tabular masses, so as to form a distinct part of that Mediterranean region, beginning in the great Shotts and extending eastwards to the meridional faults of Syria. This former northern extension or 'foreland' of Africa, which included these islands in comparatively late geological times²⁸, is further indicated by the remains of the dwarfed African mammals occurring in the cave-deposits. (See below.)

DETAILED DESCRIPTION OF THE BEDS¹

(1) The Lower Coralline Limestone has a thickness of fully 500 ft., and is divided by Cooke⁷ into a lower portion consisting of hard compact limestone and an upper portion or *Scutella* bed. This formation is as a whole semi-crystalline, but sometimes is granular, and it varies in colour from pure white to red or cream. In many cases it is almost entirely composed of nullipores (*Lithoihamnium*) and other calcareous algae, together with numerous foraminifera and fragments of mollusca, polyzoa, corals, and echinoderms. According to Murray⁵ these suggest shallow water and point to the accumulation of the materials in water of less than 50 fathoms. In the more crystalline portions no trace of organisms can be detected. Phosphatic nodules occur in the upper part.

Fossils are numerous, especially the echinoid *Scutella striatula* (from the abundance of which the upper portion receives its name), and the characteristic foraminifer *Orbitoides* (*Lepidocyclus*) *mantelli*. A large number of species of echinoids^{2 22} have been recorded, including:—

Cidaris adamsi Wr., *Cidaris oligocenus* Greg., *Echinus tongrianus* Greg.,
Breynella equizonata Greg., *Echinolampas posterolatus* Greg., *Scutella striatula* Sen.

Casts of large species of mollusca, belonging to *Conus*, *Haliotis*, *Spondylus*, *Ostrea*, *Pecten*, etc., are common. The occurrence of *Orbitoides mantelli*, also in the Vicksburg Formation of the southern United States and in the West Indies, is a noticeable feature.*

Stratigraphically the limestone is regarded as of the same age as the Tongrian of Sicily, and the age is therefore Lower or Middle Oligocene. On Gozo the rock has been quarried for ornamental marble.

(2) **The Globigerina Limestones**^{3 6 7}.—This series varies in character and thickness, and consists of beds of limestone amounting in all to 150-250 ft. separated by layers of nodules. The following lithological divisions have been recognised⁶ in descending order:—

- (a) White rotten limestone.
1st nodule seam.
- (b) Fine hard-grained limestone.
2nd nodule seam.
- (c) Compact semi-crystalline limestone.
3rd nodule seam.
- (d) Yellowish soft limestone.
4th nodule seam.

* See Chapter on the West Indies.

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PalfiBontologically the three lower divisions comprising the limestone (*d*) and the two lower nodule beds are separable from the others and are correlated with the Aquitanian (Upper Oligocene), while the rest are referred to the Langhian (Lower Miocene).

The upper beds of the series are usually of a grey or blue colour, and contain more argillaceous material than the lower ones, which are often red or rose-coloured¹. The upper beds also contain many irregular hæmatite nodules, and in bed (c) siliceous concretions are a characteristic feature. It is from the lower beds that most of the building-stone of the country is obtained.

In the lower or Oligocene portion foraminifera are very abundant, and fish-remains (*Stereodon*, *Notidanus*, *Platax*, *Oxyrhina*, *Odontaspis*, etc.) are common towards the base. The echinoid *Scutella striatula* also occurs with a few other echinoids, and the nodule bed at the top has yielded teeth of the seal *Phoca rugosidens* and many corals belonging to the genus *Trochocyathus*, etc.

The basal nodule bed consists of phosphatic nodules of irregular shapes and phosphatised casts of mollusca (especially pteropods), corals, etc., and analyses show the presence of over 31 per cent, of phosphate of lime.

The upper portion of the Globigerina Limestone series which is attributed to the Langhian or Lower Miocene is more argillaceous than the lower, containing only 50-70 per cent, of lime, and the beds pass up gradually into the overlying series of the Clays and Marls. Usually only two nodule beds are developed, but locally more may be present. Siliceous concretions (chert nodules), often of large size, occur in this division⁷, while in the uppermost bed the fossils are pseudomorphed by peroxide or phosphate of iron. The highest nodule bed has its nodules mostly composed of phosphate of iron, but in the lower nodule bed the nodules contain about 40 per cent, of phosphate of lime and about the same percentage of carbonate of lime. The nodule beds vary in thickness from a few inches to 2 ft., and the nodules themselves range in size from a pea to several inches in diameter. In colour they may be jet-black, pale brown, or greenish according to their composition. The amorphous nodules are always mixed with quantities of phosphatised remains of echinoderms, mollusca, corals, and bones of vertebrates.

The characteristic and commonest fossils of this Langhian division are *Pecten denudatus* Reuss, and *Aturia aturi* Bast, neither of which is found in the lower or Aquitanian portion of the Globigerina Limestones.

Amongst other fossils may be mentioned the following^{22 26} :—

Pecten koheni Fuchs, *Pecten cristatus* Fuchs, *Sicala melitensis* Fuchs, *Chenopus pes-pelicans* Linn., *Conus dubius* Gulia., *Terebratula sinuosa* Mant., *Brissopsis crescenticus* Wr., *Schizaster parkinsoni* DeFr., *Flabellum avicula* Mich., *Trochocyathus latero-cristatus* Edw. and H.

The vertebrates include *Tomistoma champsoides* Lyd., *Trionyx melitensis* Lyd., *Halitherium* sp., *Zeuglodon* sp., and numerous fish-remains, including *Notidanus*, *Oxyrhina*, *Carcharodon*, *Odontaspis*, *Hemipristis*, etc.

(3) **The Clays and Marls**^{8 9}, frequently called the 'Maltese Clays and Marls' or the 'Blue Clays,' consist of a series of blue and yellow clays and marls varying much in thickness, composition, and distribution. They are developed only in the north and north-western districts of Malta. In some places the beds reach a thickness of as much as 50 ft., but in others they are reduced to 3 ft. or less, but it is thought that the pressure of the overlying beds is largely the cause of these differences of thickness. They lie conformably between the Globigerina Limestones and the Greensands, but their upper surface is uneven, and in the hollows water collects and is held up by the impermeable

character of the formation so that it becomes an important source of water-supply in the islands.

The lithological transition from the underlying Upper Globigerina Limestone is gradual, and the fauna is so similar that the Clays and Marls may be considered as merely its argillaceous upper portion. Consequently they are also referred to the Langhian, and represent nearly the most westerly development of the Schlier Formation of Upper Austria, which lying between the first and second Mediterranean stages, as defined by Suess⁴, preserves a remarkable uniformity in its palæontological and physical characters the whole distance from Asia Minor (or perhaps Persia) to the neighbourhood of Nice.

A characteristic feature of these beds in Malta is the presence of ovoid or sub-spherical nodules of yellow or blue clay of a concretionary origin. Fossils are not so numerous as in the other beds, and their substance is usually replaced by peroxide of iron, but the clays are extraordinarily rich in foraminifera. The most characteristic species of fossils are *Aturia aturi* Bast, and casts of other species of Nautilidæ, the 'cuttle-bone' of a *Sepia*, and the bivalves *Pecten koheni* and *P. denudatus*. Most of the fossils are identical with those of the Upper Globigerina Limestones. The mollusca are mostly in the state of casts.

(4) **The Greensands** have usually a thickness of 20-30 ft., but in places it increases to 50 ft. The deposit is a typical Greensand, and closely resembles that forming in modern seas, containing many grains of glauconite, foraminifera, and fragments of other organisms. The upper portion consists of indurated yellow sand forming the Clypeaster bed. The abundance of glauconitic grains frequently gives the sands a black colour, but, owing to weathering, the colour is generally yellow, red, or brown.

The most abundant and characteristic fossils belong to the echinoid genus^{22 26} *Clypeaster*, and large specimens of *Cl. altus* Leske and *Cl. marginatus* Lam. are common; both species are typical of the Helvetian or Middle Miocene. Other echinoids are *Heteroclypeus hemisphericus* Greg., *H. subpentagonalis* Greg., *Echinolampas hemisphericus* Lam., and *E. wrighti* Greg. In some places the foraminifer *Heterostegina depressa* d'Orb. exists in enormous quantities, so that the rock has been called a *Heterostegina* Limestone, containing as much as 91 per cent, of lime.

The remains of sharks also are abundant, especially the large teeth of *Carcharodon megalodon*.

The readiness with which the Greensands and Clays yield to weathering causes the overlying Coralline Limestone to break off in steep cliffs, while the softer beds form the slopes at the base of the hills, as is particularly noticeable in Gozo.

(5) The **Upper Coralline Limestone** varies in Malta from 250 to 300 ft. in thickness, but on many of the Gozo hills it is reduced to a few feet. It is divisible into three portions, the upper two of which form the so-called 'Gozo Marble'—

- (a) White Coralline Limestone.
- (b) Reddish-yellow Limestone.
- (c) Soft White Limestone.

Over large areas in the west and north-west of Malta, and capping most of the higher hills of Gozo, it forms the surface-rock. The texture of the rock varies considerably, being in some cases crystalline without any traces of organic remains, but in others granular, porous, or rubbly. Murray⁵ describes it as made up of 'broken fragments of Nullipores, Corals, Echinoderms, Gastropods, Lamellibranchs, Polyzoa, Crustacea, Ostracod valves, Serpula tubes

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and many Foraminifera.' It is believed to have been deposited in shallow water at a depth of less than 50 and possibly less than 20 fathoms. As regards its palæontological features, the abundance of numerous species of *Pecten* and of echinoids (especially belonging to the genus *Brissus*) is noteworthy. Recent work on the echinoids and Pectinidæ of the Miocene beds of Malta include papers by Stefanini²² and Roman and Roger²⁶. Amongst the fossils the following may be mentioned :—

Pecten pandora Desh., *Pecten burdigalensis* Lam., *Pecten beudanti* Bast., *Pecten scabrellus* Lam., *Pecten varius* Lam., *Terebratula sinuosa* Mant., *Megerlea truncata* Linn., *Argiope decollata* Chemn., *Cidaris melitensis* Wr., *Echinus duciei* Wr., *Clypeaster altus* Leske, *Amblypygus melitensis* Wr., *Echinolampas hemisphericus* Lam., *Brissopsis duciei* Wr., *Schizaster scillæ* Desm., *Prenaster excentricus* Wr., *Brissus latus* Wr., *Brissus imbricatus* Wr., *Brissus tuberculatus* Wr., *Brissus oblongus* Wr., *Brissus depressus* Greg., *Spatangus delphinus* DeFr.

The Upper Coralline Limestone belongs to the 'Second Mediterranean Stage,' and is correlated with the Tortonian of the Apennines or the Leithakalk of the Vienna basin which it often closely resembles in petrological appearance⁹.

Faunistic Peculiarities of the Maltese Tertiaries⁶.—The Maltese Islands are on the border-line between the eastern and western Mediterranean provinces, each of which in Middle Tertiary times possessed peculiar characters in its fauna and stratigraphical succession. There is a mixture of these two types in Malta complicated by the existence of numerous local species. For in this intermediate area the conditions of deposition and environment were continually changing, and local subsidences and elevations of the sea-floor led to the formation of more or less isolated basins which developed specific differences in their inhabitants. The development of numerous peculiar species is a feature not only present in Malta, but also in Corsica and Sicily at the same period, and is particularly noticeable amongst the echinoids. Certain points in the correlation of the Maltese beds with those of southern Europe have accordingly been the subject of much discussion, though the age of the Lower Coralline Limestone, the Greensands, and the Upper Coralline Limestone is a matter of general agreement. It is difficult, if not impossible, to draw a sharp line of division between the Oligocene and Miocene in this region, for there is a gradual passage from one to the other through the upper part of the Globigerina Limestones and Blue Clays,—a continuous series of deep-water deposits bridging over the interval. Consequently an earlier appearance of deep-water Miocene forms is observable in Malta (according to Gregory⁶) than in the Vienna basin, and this renders a precise correlation of the beds in the two areas a matter of difficulty. There are numerous affinities between the marine faunas of the Miocene of Malta and the contemporaneous beds of the North African coast²⁷ and indeed of the whole Mediterranean area in spite of local peculiarities.

Another peculiarity of the Tertiary faunas of the Maltese rocks consists in the extraordinary resemblance or even identity of certain species with those occurring in beds in the West Indian Islands^{10 11 30}. The faunistic relations of the Antillean and Mediterranean areas extend also to some Mesozoic formations. Haug suggests a geosynclinal stretching across the Atlantic between the so-called North Atlantic and Africano-Brazilian continents in the Nummulitic epoch to account for these zoological and stratigraphical affinities. The history of the Atlantic Ocean^{4 29} is closely related to the distribution of the marine faunas in Tertiary times, and in Miocene times the echinoids³⁰ and corals are held to point to a shallow-water connection between the eastern

and western land-masses^{4 29 30 31}, a certain number of the same species occurring in the Maltese, West African, and West Indian Miocene.

Later Tertiary History of the Maltese Islands.—After the close of the Upper Miocene and the end of the Second Mediterranean Stage, this marine area was broken up by the elevation of a portion of the sea-floor into dry land so as to form part of northern Africa, in which the Maltese Islands were at first included. Subsequent dislocations of later date cut them off from the southern continent, but in spite of movements of considerable extent in adjoining regions and of minor oscillations of the sea-level around them, there is no evidence that the islands were ever again completely covered by the sea, and there are no Pliocene or later marine deposits on their surface. But there is evidence from the abundant land-fauna, the remains of which occur in the caves and fissures, that the islands were connected at one or more periods with Africa and formed one of the land-bridges between it and Europe during part of Pleistocene times. The precise date of the final severance of the Maltese 'horst' from Africa and Sicily is somewhat uncertain^{17 28}, and from which land area it was first cut off has not been proved. The present depths and contours of the channels between the mainland and the islands may be partly a result of marine denudation during the movements, though they are probably due in the main to the tectonic disturbances and fractures^{21 23}.

Pleistocene and Recent Deposits, (a) (cave-deposits).—The caves and fissures which occur in the solid limestone rocks, mostly near the coast, contain various types of deposits, such as stalagmite, limestone-breccia, loams, red earth or clay filled with angular blocks, and occasionally layers of rounded boulders of large size. Neither the caves nor their deposits are all of the same age. The great antiquity of some of the caverns is indicated by the amount of erosion which has taken place since they were occupied by large vertebrates, and since the accumulation of the materials on their floor took place. In the case of the Har Dalam²³ cave the bottom of the gorge is now 40 ft. below its entrance, though the stream carried large boulders into it when it flowed at its level in pre-historic times'. Amongst the other well-known caves may be mentioned the Crendi, Zebbug, Melliha, Mnaidra, and Malak caves, and the Gandia fissure, and these have yielded numerous vertebrate remains³² from their ossiferous breccias^{12-15 18 19}. The most interesting vertebrates are the dwarf species of hippopotamus allied to the African tetraprotodont *H. amphibius*, and the pygmy elephants²⁸ (of which the adults were only 3-6 ft. high) allied to the modern African species. The three species of pygmy elephant are, however, now considered to be dwarf races of the European *E. antiquus*. A huge dormouse (*Leithia (Myoxus) melitensis*) and some birds and reptiles are also found. The following species may be mentioned :—

Hippopotamus pentlandi H. v. Meyer, *Hippopotamus minutus* Blainv., *Elephas melitensis* Pale, *Elephas mnaidrensis* Leith Adams, *Leithia (Myoxus) melitensis* Leith Adams, *Ursus ferox* Rich²⁰, *Canis* sp., *Cervus elaphus*, var. *barbarus*, *Cygnus falconeri* Park., *Gyps melitensis*, *Grus melitensis*, *Testudo robusta* Leith Adams, *Testudo spratti* Leith Adams.

It is believed that all the above species lived at the same time on the islands and belong to the older Pleistocene²⁸. But a later fauna containing *Cervus dama*, *Equus*, *Arvicola*, etc., is also represented in the caves, and the upper layers contain human artefacts^{18 19}. It is believed that the long-continued isolation of the islands owing to the severance of the land-connections led to the development of the numerous peculiar species of mammals, as in the case of Cyprus. Their final extinction was probably a result of one of the changes of

climate of which the evidence is clearer in other parts of the Mediterranean and southern Europe than in Malta itself. But the occurrence of limestone agglomerates of similar lithological and physical characters to those in Gibraltar indicates the existence at one time of a severer climate when the solid limestone beds suffered considerable destruction by frost, leading to the formation of extensive screes. The blocks of limestone in these agglomerates are sub-angular or rounded, and imbedded generally in clay. These breccias usually are found at the foot of the fault-cliffs or along the coast¹⁶, and are in many cases distinctly stratified. Remains of the pygmy elephants and hippopotamus have been recorded from them as well as from the caves.

(b) *Other Deposits*.—There are also some other superficial deposits^{3 15 18 23} found on the higher slopes of the plains and plateaus and due to sub-aerial waste. These consist of unstratified layers of angular detritus and thin inter-stratified loams. On the floors of the valleys there are stratified sands, loams, and gravels of fluvial origin, which suggest a greater intensity of the denuding agents and a more abundant rainfall than at present prevails, and they occasionally contain land-shells (*Helix*, etc.). Trechmann²³ recognises the evidence of pluvial periods in the Quaternary deposits, and also of arid conditions as suggested by the reddened or blackened limestone pebbles indicating intense solar radiation.

ECONOMIC GEOLOGY

Phosphates¹⁸.—In addition to the definite seams of phosphatic nodules intercalated in the Globigerina Limestones, nodules of the same character are frequently scattered through these beds. They contain from 31 per cent, to 40 percent, of phosphate of lime. The seams themselves vary from a few inches to 3½ ft. in thickness.

Building Stones.—More than one of the Tertiary limestones are used for building, and the Gozo marble is an example of one of the ornamental stones which they furnish.

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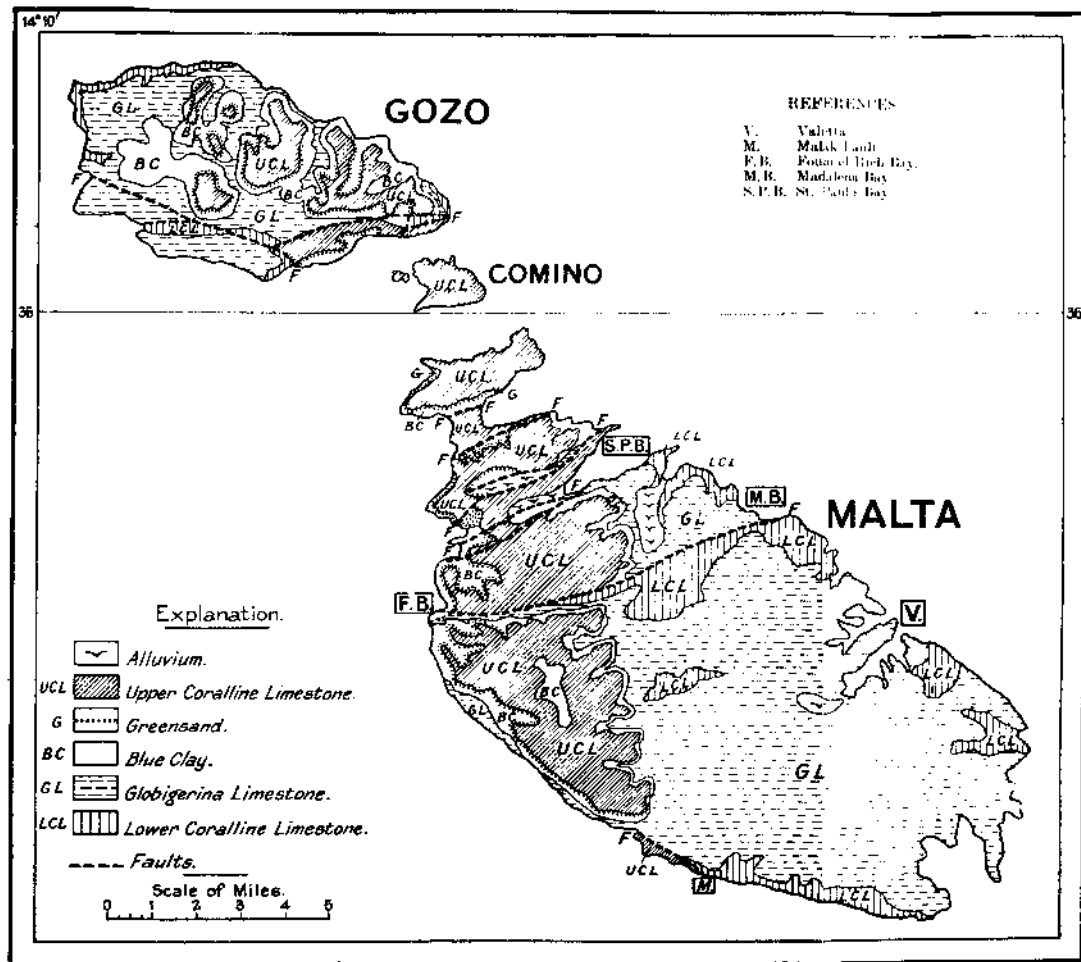


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SECTION III.—CYPRUS

Physical Characters.—The island of Cyprus has a length of about 140 miles, while its greatest breadth is about 60 miles. A large undulating plain, called Mesaoria, occupies the central part of the island, and it is bounded on the north by the long narrow range of the Kyrenia Mountains, which run parallel and close to the northern coast and are prolonged to form the north-eastern promontory of the Karpas. Both flanks of this range are steep, and it possesses heights rising to over 3000 ft. On the south side of the Mesaoria plain is the large and broad mountainous mass of the Troodos and other mountains, their loftier summits attaining a height of more than 6400 ft. The island is surrounded by deep water, and is not connected with the neighbouring lands by submerged banks as in the case of the Maltese Islands, except on the north-east, where the peninsula of Karpas points directly to the Amanus Mountains of the Taurus System, having the same general easterly or north-easterly trend, and it is separated by a distance of only 60 miles from the Syrian coast.

General Geological Structure^{12 3 51519 20 2122.}—The axis of the northern range of mountains consists of much disturbed and frequently altered limestones of Palaeozoic²¹ and Mesozoic age, while its northern and southern slopes are composed mainly of sandstones and marls overlain by white limestones, all of which are of Eocene, Oligocene, or Miocene age. The central plain is largely covered by Pliocene and Pleistocene deposits, which also occur in patches in other parts of the island, and rest unconformably on the older rocks. The Troodos Mountains consist of igneous rocks of pre-Miocene or late Miocene age, many of which are of a volcanic nature. South of these mountains the white Miocene limestones and marls have a further considerable development; Pliocene deposits are also widespread and are mostly undisturbed, though in places they occur at a considerable elevation, pointing to post-Pliocene earth movements. The statement that west and south of the Troodos Mountains there is an area of metamorphic rocks and crystalline schists has been made by Saqui¹⁵ and was suggested by Gregory²⁹, but confirmation of this occurrence is awaited. Gregory, indeed, expressed the opinion that they were the continuation northwards of the old metamorphic and crystalline rocks of Egypt, striking almost at right angles to the trend of the Tauric folds.

Structural Relations^{4 16 21 31.}—The island of Cyprus forms part of the great 'Tauro-Dinaric arc,' constituting the important south-

eastern loop of the Alpine folds. It branches off from the main European mountain system in the Eastern Alps to run down the eastern coast of the Adriatic through Greece, and after an interruption in its continuity by submergence, subsequent to its formation, is traceable through Crete, bending here abruptly from a south-easterly to an easterly direction. It is then continued after another interruption through Cyprus by way of the northern mountain range, and then beneath the intervening sea to the mainland of Asia, where it appears to be continued to the north-east by the mountains situated between Antioch and Alexandretta in northern Syria, and thus is connected with the Taurus Mountains. The northern range of mountains in Cyprus is a continuation of the outer (marginal) zone of the Tauric folds¹⁶ which have been pushed southwards over the edge of the Syrian tableland. The severance of the island of Cyprus from the mainland and the breaking up of the Alpine mountain arc, and of the land-area of which the island formed a part, belong to the series of movements which affected the eastern Mediterranean in late Tertiary times.

DETAILED DESCRIPTION OF THE GEOLOGICAL FORMATIONS

STRATIGRAPHICAL SUCCESSION

	Pleistocene	. Alluvial deposits, sandy limestone, sands, and conglomerates	up to 50 ft.
	Pliocene	. Shelly limestones with calcareous sands and sandstones .	100-150 ft.
		Period of igneous activity.	
	{	Miocene . White, shelly, or chalky limestones, and marly chalk with layers of flint .	about 1000 ft.
		Oligocene ? . Grey and yellowish marls with beds of gypsum	400 ft.
Kythrean	(Upper Eocene or Oligocene)	Grey felspathic sandstones and sandy shales	? 1500 ft.
	Eocene	. Greenish shales with hornstone bands (Lapithos beds)	? 100 ft.
Trypanian	Mesozoic and Upper Palæozoic	Grey limestones and dolomites, white and pink marbles, both massive and laminated	possibly 5000 ft.

The names Trypanian, Kythrean, and Idalian were applied by Bellamy³⁵⁷ to certain natural stratigraphical groups or lithological series of rocks in the island, the precise correlation of which is at present a matter of some uncertainty. Recently it has been recognised by Raeburn³⁵ that there are at least three unconformities in the succession of Tertiary rocks in Cyprus, one at the **base** of the Eocene (Lapithos beds), a second between the Oligocene (Kythrean) and the Miocene (Idalian), and a third between the Miocene and Pliocene.

Trypanian Series.—The compact limestones and dolomites of this composite series, which occur in the Kyrenia range, have suffered much disturbance, but in general form an anticline. They are generally much altered by intense compression and are pierced in places by igneous intrusions of the quartz-felsite type which have metamorphosed them. Occasionally they are schistose. In appearance some of them resemble the Hippuritic Limestone of Attica. It is only recently²¹ that it has been proved that Hippuritic limestone of Cretaceous age occurs, and that even older limestones of Triassic, Carboniferous, and Permian age are involved in the Trypanian Series. Foraminifera of typical Upper Palaeozoic genera have been recognised. Beds similar to these in the Kyrenia Range are present on the mainland in Asia Minor and Syria, as well as in the Island of Rhodes³³. The true thickness of the limestones and associated rocks of the Trypanian Series is unknown, but it has been estimated at 5000-6000 ft.

Although their main development is found in the northern chain, small inliers of them occur in the extreme south-west of the island.

The limestones are generally grey, bluish, or brownish in colour, and some are bituminous. Others are yellow, pink, white, or veined, and where pierced by intrusive igneous rocks are often completely marmorised; many decorative marbles have been obtained from this series of altered calcareous rocks.

Lapithos Beds.—In the western half of the Kyrenian range are fissile limestones, homstones, calcareous shales, shaly limestones, marls, and layers of flint, which are intimately associated with the compact limestones above described, and not clearly unconformable to them. At Lapithos they have yielded *Nummulites*, *Alveolina*, *Orbitoides*, and *Amphistegina*?, and are of Eocene age²². These Lapithos beds were formerly⁸ included in the Trypanian, but are now separated and are found²¹ to be traceable along the whole Kyrenia Range from west to east. They have also suffered earth movements which did not affect the later Tertiary beds.

Kythrean Series.—The Kythrean rocks or Flysch Series, as a whole, yield no fossils except a few tests of *Globigerina*, *Textularia*, etc.⁸⁰, and in places the pteropods *Balanium* and *Vaginella*, and are mostly regularly bedded calcareous brownish or grey sandstones, some of which consist entirely of volcanic debris embedded in a calcitic matrix and resemble the Macignos of Italy. At the base of the series are breccias and conglomerates composed of fragments of the Trypanian limestones, and at those localities where the Lapithos beds occur contain fragments of the latter as well. Probably an unconformity of some importance separates them, as Raeburn³⁵ now states is the case. At the top of the Kythrean Series are greenish or greyish marls.

The beds are frequently folded and tilted at various angles and form undulating ground. Their chief development is along the south side of the Kyrenia Mountains, and they are estimated to be from 1500 to 2000 ft. thick. The same Flysch-like facies of the Eocene is found in the Taurus Mountains¹⁶. Kober¹⁶ correlates the Kythrean Series definitely with the Oligocene.

Idalian Series.—Overlying the Kythrean Series is a series of marls and white, well-bedded, chalky limestones termed the Idalian Series. The white calcareous rocks of this series extend over nearly one-half of the island, and are well developed south of the Troodos Mountains; they are conspicuous from their intense whiteness, and are the most characteristic formation in the island. The total thickness of the beds is about 1400 ft., but their lithological characters vary considerably. The lowest beds are argillaceous and consists of about 400 ft. of grey and yellowish marls, containing beds of gypsum and alabaster, with occasional veins of sulphur. This lower division,

which is well developed along the southern side of the Karpas Peninsula, and west of Larnaca, is doubtfully referred to the Oligocene. The limestones are stated to be precisely similar to those of definite Miocene age in northern Syria; some are marly or chalky, others are hard and shelly, and bands of flint are frequently intercalated. Some of the limestones are composed almost entirely of tests of foraminifera, especially *Globigerina*, like the Maltese Globigerina Limestones. The characteristic Langhian nautilid, *Aturia aturia*, and the echinoid *Brissopsis crescentinus*, which also occur in the Langhian of Malta, have been found in them, and Gaudry¹ and Bergeat⁶ recorded a few other fossils. A considerable fauna of lamellibranchs²⁵, with a few gastropods, echinoids²⁵, and corals²⁷ has been recently recorded, representing both the Lower, Middle, and Upper Miocene, and including species found in Asia Minor, Syria, Persia, Egypt, Malta, and Cyrenaica, but especially in Cilicia²⁵, and Syria⁸¹.

At Cape Pyla the upper shelly limestones are^{3 10} richly fossiliferous, and have yielded the echinoid *Clypeaster alius* var. *portentosus*, a species which is characteristic of the Helvetian and occurs abundantly in the Greensands of Malta. These limestones, which are the highest Miocene beds so far recognised in the island, are largely composed of fragments of *Lithothamnium*, echinoids, polyzoa, and mollusca with abundant foraminifera³⁰, amongst which *Orbitoides* is the principal form from Cape Greco. The *Clypeaster* horizon has been recently discovered near the west end of the north side of the Troodos Mountains²⁴, with a rich fauna of mollusca as well as the typical echinoid and foraminifera³⁰.

Igneous Rocks.—The igneous rocks are of many different types, but there is no general agreement^{18 19 20 22} as to their ages or relations to one another and to the Tertiary and older rocks with which they are associated. Cullis and Edge^{18 19} have recognised three main types of igneous rocks: (1) the pillow-lavas¹⁹, which are chiefly andesites and are the most abundant; (2) the serpentines; and (3) the diabase of the Troodos. Some other and smaller masses of intrusive rocks (syenite, quartz-felsite²², etc.) are believed to be pre-Tertiary, and the fact that the Kythrean Series is largely made up of volcanic debris supports this view. Kober¹⁶, however, considers that the andesitic and trachytic lavas in Cyprus are of Oligocene age, but the serpentines are probably post-Trypanian and possibly Cretaceous like those on the Asiatic mainland, though Cullis and Edge believed that in places they invaded the lavas. The diabase¹⁷ of the Troodos Range is regarded as pre-Idalian. Peridotite masses are stated to be intrusive into it³⁸. The author²² agrees with Kober that the serpentines and associated ultrabasic rocks are earlier than the pillow-lavas, though post-Trypanian in age. Some of the pillow-lavas are clearly contemporaneous flows in Idalian times, but others appear to have been erupted somewhat earlier and to be pre-Idalian, having suffered erosion. The local silicification of some of the Idalian beds must be attributed to later hydrothermal action¹³. But as there is no sign of alteration by igneous rocks of any of the Pliocene beds, all the igneous activity must have come to an end before they were deposited.

The main centre of development of igneous activity was the Troodos Mountains, which are almost entirely composed of intrusive or volcanic rocks. The area of mountainous ground extends for a distance of about 60 miles with an average breadth of 17 or 18 miles, and includes the Tillyria Mountains on the west, the Adelphi and Troodos ranges in the centre, and the Machera group on the east. These central mountains constitute the loftiest ground in the island.

The most abundant rock is diabase, but serpentine occupies the region of

the highest parts of Troodos. Gabbros, peridotites, harzburgites, etc., are also found. Of volcanic rocks basalts are of frequent occurrence, and andesites, liparites, trachytes, with beds of ashes and tuffs, have also been observed¹⁷. It is in these igneous masses that the copper deposits of the island are situated^{15 18 19 32}. In places the serpentines contain asbestos, chromite, and magnesite.

Pliocene.—The Pliocene deposits (which are not always easy to separate from the Pleistocene) consist of shelly limestones and calcareous sandstones, together with some bluish clays, friable sands, and conglomerates which contain pebbles of diabase. They all lie in a horizontal or slightly inclined position, and are mostly confined to the central plains of the island or to the coastal margin, but some occur up to a height of about 1000 ft.²² Lower, Middle, and Upper Pliocene beds²² are widely spread, but the majority of the deposits belong to the Plaisancian and Astian²² and contain an abundant fauna^{1 26 28} of lamellibranchs and gastropods, with some echinoids and foraminifera. All the beds are of marine origin. The fauna corresponds in general character with that of southern Italy and Sicily and has a typical Mediterranean facies. The thickness of the beds varies much, but in places is estimated at 350 ft. The fauna of corresponding beds on the Island of Cos³⁴ is closely allied, containing many of the same species of mollusca.

The Pliocene beds are sometimes compact and durable, and a fine yellow freestone is quarried at Kyrenia and near Limasol as a building stone.

Pleistocene—(a) *Marine deposits* of Pleistocene age occur as shelly sandstones, conglomerates, pebble-beds, sands, and sandy limestones. Raised beaches and terraces indicate recent crustal movements. The famous salt-lake of Larnaca⁷ occurs in a depression of Pleistocene marine fossiliferous sandstones and conglomerates through which the sea-water percolates, and it probably marks the site of a former estuary. Some of the oyster beds on the surface of the ground between Nicosia and Limasol and near Kykko monastery are probably of Pleistocene age²², and represent late incursions of the sea.

(b) *Of Sub-aerial accumulations* there are great breccias composed of blocks of limestone and other rocks, all water-worn and frequently cemented together into a solid mass. These deposits occur on both sides of the Kyrenia range, and have probably, originated under severer climatic conditions, the materials having been subsequently swept down to the lower ground and worn by torrential action.

(c) *Alluvial deposits* laid down by flood-waters are still in process of formation in the Mesaoria.

(d) *The Cave-deposits*, which are of the usual type, are of peculiar interest because of the mammalian fauna which they have yielded⁸⁻¹². Some of the caves which have been explored are situated on the southern slopes of the Kyrenia hills, but others occur on Cape Pyla in the south-east part of the island. A pygmy elephant (*Elephas Cypristes* Bate) showing no affinity to the African species, and more allied to *E. antiquus* and *E. meridionalis*, has been found; also a pygmy hippopotamus (*H. minutus*) and a new species of genet (*G. phsictoides*). The hippopotamus is more closely allied to the still surviving Liberian species than to any of the other dwarf forms of the Mediterranean islands. It has been suggested that some climatic change may have caused the extinction of this mammalian fauna. Whether the small size of these animals is a survival of a primitive condition rather than a highly specialised characteristic due to isolation is doubtful¹².

Summary of Physical History of Cyprus³²⁰.—Much of the folding and faulting of the Palaeozoic and Mesozoic beds in the Northern

Range^{20 21} took place in pre-Tertiary or early Tertiary times, probably at various periods. As above-mentioned there were earth-movements accompanied by folding after the deposition of the Lapithos (Eocene) beds and before the Oligo-Miocene period. But the chief orogenic disturbances were post-Miocene. In late Eocene as well as in pre-Eocene times the island was united to other tracts of similar lands in Greece, Asia Minor, and Syria. Subsidence and erosion of the land then took place, furnishing the materials and the conditions for the formation of the Kythrean conglomerates and other beds. The subsidence continued during the greater part of Miocene time till the ancient land-surface was buried beneath several thousand feet of marine sediments comprising the Idalian Series. At the close of the Miocene an elevation of the sea floor took place accompanied by much folding and compression of the strata by a thrust from the north, resulting in the formation of isoclinal or overturned overfolds on the south side of the northern range¹⁶, affecting the Trypanian, Kythrean, and Idalian beds²⁰. The orogeny was part of the Tauro-Dinaric arc of the Alpine fold-system of southern Europe and Asia Minor. The Troodos Range also owes its formation largely to earth movements of this period. But parts of the island appear still to have been submerged, though Cyprus on the whole at this time seems to have been connected with the mainland of Asia on the east. During the whole of the Pliocene period submergence to a minor extent took place, but the mountain ranges stood up as islands. The extent of this subsidence varied, but the middle part of the island was certainly occupied by the sea¹⁹.

By recent geophysical prospecting³⁵ it has been found that there is an ancient buried river system sub-parallel to the present rivers, and cut in the grey clay of the Idalian (Miocene) formation. It is filled with coarse gravels, sands, and silts, but shows no trace of its existence on the present surface of the ground. From the widespread occurrence in the Mesaoria of marine Pliocene deposits, some of Plaisancian age, it seems that the excavation of these river-channels must have taken place during an elevation of the land in late Miocene rather than in Pliocene times.

An uplift of the whole Mediterranean area to a considerable extent subsequently took place in early Pleistocene times, several causeways³⁶ being formed between Europe and Africa, and a mammalian fauna invaded these newly-formed lands. By one of the bridges thus instituted the vertebrates now found in the cave-breccias were probably introduced into Cyprus, but the connection in the case of Cyprus is now thought to have been rather with Asia or Europe than with Africa, judging from the affinities of the mammalian remains³⁶.

Subsequently the land-connections were severed by a fresh subsidence, apparently at an earlier date than that at which Malta was cut off from Sicily, and climatic changes supervened, so that the highly specialised pygmy species of mammals became extinct. Finally, the land again suffered small and intermittent upward movements, as the Raised beaches testify.

ECONOMIC GEOLOGY

Copper.—Copper-ores³⁷, chiefly copper-bearing iron-pyrites, are found in the diabase and pillow-lavas³⁹ of the Troodos Mountains^{13 18 19}. The chief deposit worked is at Skouristissa^{18 32 39 40}.

Umbur occurs along the outcrop of the Idalian-igneous contact in various places in great quantities, and seems to consist of marls impregnated with iron and manganese.

Building Stones.—The Idalian limestones are used in places for building stones, and near Athiaenou a soft freestone is used for making stone troughs and other vessels as well as firebricks¹⁹.

Chromite.—There are deposits of chrome-ore of value in the serpentines and basic plutonics of the Troodos Mountains which are worked to a small extent¹⁹.

Magnesite.—The serpentines also contain magnesite in the Akamas Peninsula.

Water Supply³⁵.—The chief source of the water supply is from springs in the Kyrenia Mountains, and in other districts from Pliocene and Pleistocene deposits. But the conservation of the rainfall in catchment basins and reservoirs has been tried. The bore-hole at Morphou in coastal beds has yielded a fairly abundant supply, but there is no proof of the structure of the Mesaoria providing artesian water.

Asbestos^{14 17 19 38}.—The chrysotile variety (probably the amiantos or Karystian stone of the ancients employed for textile purposes) occurs as small veins along shear zones in the serpentine of the Troodos Mountains¹⁷ in very short fibres, 1 cm. long, and is similar to the Thetford asbestos of Canada. The serpentine forms a marginal ring round the intrusive masses of peridotite.

Gypsum¹⁹ and alabaster occur associated with the Idalian (Miocene) beds, especially along the south side of the Karpas Peninsula.

Marbles and decorative stones of beautiful and varied characters are a special feature of the Trypanian Series.

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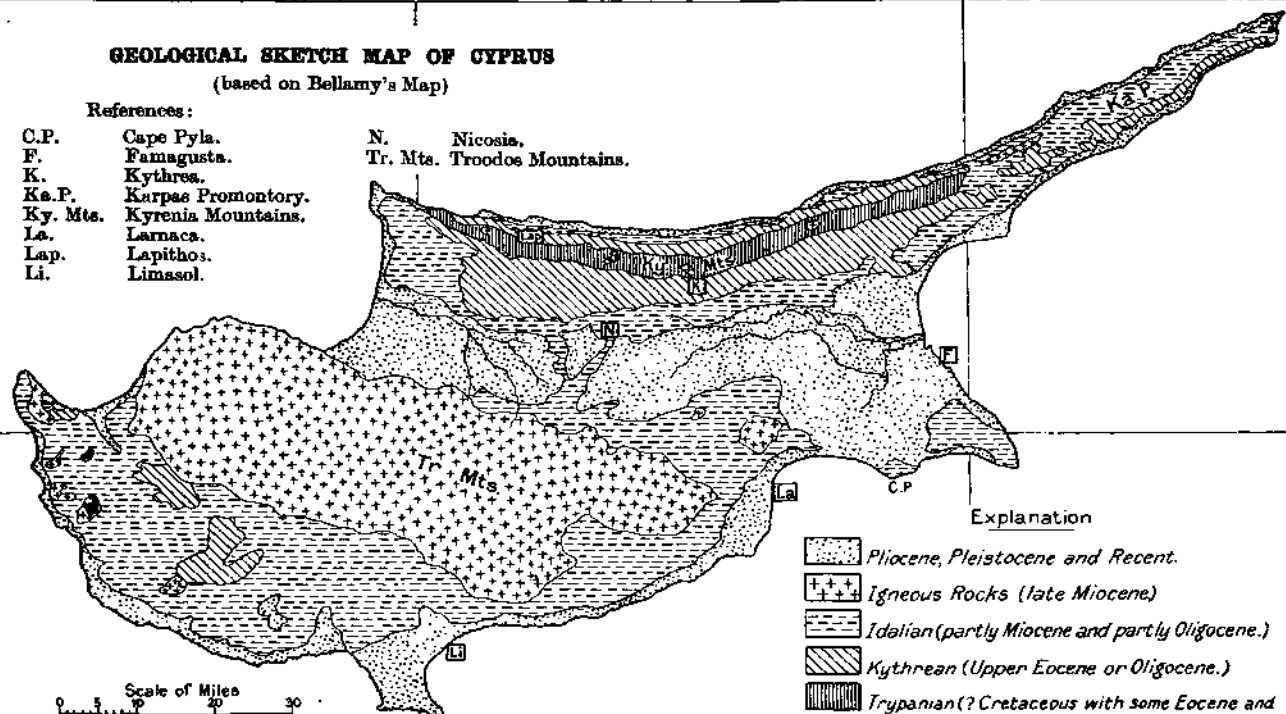
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GEOLOGICAL SKETCH MAP OF CYPRUS

(based on Bellamy's Map)

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C.P.	Cape Pyla.	N.	Nicosia.
F.	Famagusta.	Tr. Mts.	Troodos Mountains.
K.	Kythrea.		
Ka.P.	Karpas Promontory.		
Ky. Mts.	Kyrenia Mountains.		
La.	Larnaca.		
Lap.	Lapithos.		
Li.	Limasol.		



Explanation

- Pliocene, Pleistocene and Recent.
- Igneous Rocks (late Miocene)
- Idalian (partly Miocene and partly Oligocene.)
- Kythrean (Upper Eocene or Oligocene.)
- Trypanian (? Cretaceous with some Eocene and Palaeozoic.)

CHAPTER II

THE ANGLO-EGYPTIAN SUDAN

The Anglo-Egyptian Sudan, though intimately connected geologically with Egypt, belongs mainly to the Great African plateau, the ancient crystalline rocks of Upper Egypt^{1 2 22-25 31 32} linking them together. On the whole, however, the geological history of these two areas is distinct, Tertiary rocks³⁰ being almost entirely absent in the Sudan, which also lies beyond the south end of the shallow synclinal on which most of Egypt is situated. Some Palaeozoic and Cretaceous beds (formerly all grouped under the name *Nubian Sandstone*) occupy certain areas, but no marine deposits of Palaeozoic or Mesozoic age have so far been discovered, and the absence of the thick calcareous marine and fluvatile deposits of Tertiary age, which are so well developed in Egypt, is a conspicuous feature. The greater part of the Northern Sudan is composed of the Basement complex of metamorphic and igneous rocks. The southern parts of the Sudan south of Khartum and adjoining Abyssinia and Uganda have a different geological character.

Archaean, Pre-Cambrian and old intrusive rocks.—(The Basement Complex).—A great variety of petrological types and rocks of various pre-Palaeozoic ages is comprised under this heading, the precise succession, correlation, and classification of them being only broadly ascertained. Hume³² divides the Archaean and the Pre-Cambrian of Egypt and the Northern Sudan into three groups or cycles, the oldest being named the *Protarchæan* which includes the basement gneisses and granites. The succeeding group he terms the *Metarchæan* which are sedimentary deposits much metamorphosed, but with an almost general absence of limestones. Plutonic intrusions are typical. This group is regarded as equivalent to the Lower Algonkian of America and the Dharwar of India. The uppermost and latest group is called by him the *Eparchæan* representing the Upper Algonkian, and is considered as equivalent to the Transvaal System of South Africa, and the Karagwe-Ankolean of Central and East Africa (*q.v.*). It is chiefly siliceous in character and is marked by conglomerates. Later than these are the intrusions of certain igneous rocks, including diorite as well as hornblende- and biotite-granites on the Nile, which are termed *Gattarian* or late Pre-Cambrian. Still later are the pink porphyritic and muscovite granites, with dykes of various types and quartz-veins in the Cataract region. The whole area seems to have been a land-mass since the folding and metamorphic processes at the close of the Pre-Cambrian.

North of Khartum the Protarchæan gneisses are widely distributed along the great S-shaped course of the Nile, and are invaded by granite intrusions of various types and ages. The harder bands of gneiss and igneous intrusions

are the main cause of the many cataracts, but the structural folds of the rocks also play a part in their formation. At the Shabluka or 6th cataract about 60 miles north of Khartum there are ancient banded rhyolites with coarse agglomerates and schistose serpentinous rocks¹⁰; the columnar felsites are here a conspicuous feature. At the Ambigol and 2nd cataracts the diorites, as in the eastern desert, are intrusive into the Archaean schistose and volcanic rocks. The dolerite dykes also invade them, while the aplite and pegmatite dykes seem to be the latest intrusive rocks.

Between Kosha and Firket the Nile Valley is occupied by mica schists, while at the Tanjur Cataract marble bands occur in the gneiss, and near the Semna Cataract¹² hornblende schists and pyroxenite are found.

On the north-west frontier^{7,30} of the Anglo-Egyptian Sudan in the Libyan Desert and the adjoining region to the north and west, the Archaean and Pre-Cambrian metamorphic rocks comprising gneisses and schists are acutely folded, while the plutonic masses as well as the later intrusive pegmatites, aplites, and quartz veins are unfolded. The latest intrusions are the hypabyssal rocks which include porphyrites, and they may be Pre-Cambrian in date. The rhyolitic rocks are long posterior to the metamorphism of the ancient rocks and are of uncertain age, but probably are of pre-Carboniferous age, as are those of Uweinat^{30,49}.

In the Etbai Hills²³ the Protarchæan rocks are mainly calcareous schists as exposed at the Amara Cataract³².

In the southern parts of the Libyan desert the old crystalline basement is exposed over large areas⁴⁵, and Menchikoff³⁴ and Willman⁴⁹ have described the petrology of the rocks especially towards Uweinat; while on the western side of the frontier Denaeyer³⁸ and others have particularly studied them. In the Didinga Mountains²⁹ there are great masses of crystalline limestones of uncertain age, while in Darfur³ and Kordofan² phyllites, quartzites and rarely limestones of Algonkian age have been recorded, while intrusive biotite granite, granite porphyry, and gabbros, with dykes of aplite, tinguaita, and troctolite have been observed.

In the desert east of the Nile³⁰ between latitudes 20° and 22° N. and longitudes 32° and 34° 30' E. the country is composed of grey granite, with an extensive series of micaceous, talcose, and hornblendic schists, shales, clays, slates, and crystalline limestone resting apparently unconformably on it. Above these, after a long break, is a formation of (Eparchæan) conglomerates, sandstones, argillaceous limestones, and various coloured shales of uncertain age, but probably representing the Hammamat Series of Egypt. The *Nubian Sandstone Series* (including the true "Nubian Sandstone"), rests on these with a decided unconformity. The granite and schists are penetrated by dykes and massive igneous intrusions which apparently do not invade the succeeding (Pre-Cambrian) formations. Gabbros, diorites, and diabase, felsites, basalts, and porphyrites are also associated with the schists and crystalline rocks.

In the Kassala Province⁶ the oldest rocks are different and consist of a series of altered sediments comprising chlorite schists and quartzose rocks, with phyllites and very rare thin bands of marble. Into these were first intruded serpentines which have been metamorphosed in places into talc-carbonate masses. Chromite and iron-ore occur in them as lenses. There are also some intrusions of highly altered gabbros. Of later date are the intrusive granites of the south-west and north-west, and associated with them are dykes of pegmatite and quartz-veins which cut the serpentines. A newer series of intrusions of gabbro occurs in the central area, and dykes of dolerite and basalt are seen in places in the eastern parts, while at Sim-sim in the south-east there is a hill of fresh riebeckite-trachyte.

Palaeozoic.—The Palaeozoic consists mainly of sandstones which were formerly included in the so-called 'Nubian Sandstone,' but this term is now restricted to the Cretaceous portion of a composite group of beds to which the name *Nubian Series* is applied and denotes the whole group of arenaceous beds of more than one age in the Sudan and Egypt.

The Lower Palaeozoic sandstones occur in places far west of the Nile and across the western frontier. They are of massive character, white or buff in colour, occasionally false-bedded, and lie unconformably on the Basement complex. No fossils have been found in them.

The Upper Palaeozoic sandstones (*Carboniferous*³) yield lepidodendroid and other plant remains indicating a Carboniferous age, as found near Uweinat³⁰, and they are separated from the Lower Palaeozoic sandstones by a thick mass of rhyolite. No marine Carboniferous has been found in the Sudan, but in Egypt marine fossils of Carboniferous age have been recorded in one area. Above these sandstones comes the Nubian Series (see below).

Mesozoic.—The Cretaceous is represented by arenaceous deposit constituting the *Nubian Sandstone* proper. It varies locally in lithological character. It enters the Sudan from Egypt near Wadi Haifa and stretches eastwards to and beyond the Abyssinian frontier from Korosko towards Kassala^{24 25}. West of the Nile it extends from Khartum into Darfur⁷, where it occupies most of the northern part and has yielded Lower Cretaceous plant remains.⁴ Silicified wood is very common in it. The formation includes highly-ferruginous white or multi-coloured fine- or coarse-grained sandstones with occasional pebble-beds, shales, and layers of clay. The beds are mostly horizontal and usually rest directly on the crystalline basement with a strong unconformity, but occasionally they rest on the massive Palaeozoic sandstones. The plant-remains from these Darfur⁴⁷ beds include *Weichselia reticulata* (Stokes and Webb), *Frenelopsis hoheneggeri* (Ettingshausen), and *Dadoxylon aegyptiacum*, Unger.

There is a great mass of the Nubian Series forming the relict plateau of the Gilf Kebir⁴⁴ and extending to the south of it⁴⁵ on the western frontier, where isolated intrusions of basalt and hills of basalt also occur²⁸ (see below). There is evidence of denudation and erosion at several stages in the deposition of this series, and the conglomerates of silicified sandstone or quartzite seem to be derived from the Palaeozoic sandstones in this western region, but near the Nile the basal conglomerates are typically composed of pebbles of granite, gneiss, and quartz.

In southern Egypt Upper Cretaceous marine fossils, including species of *Inoceramus*¹⁸, occur in the Nubian Series, so that its deposition must have lasted for a considerable period and may include some pre-Cretaceous (? Jurassic) beds. But no such invasion of the sea has been recognised in the Sudan.

Tertiary.—Lower Tertiary rocks as boulders have been found in the Province of Berber^{5 15 27} at Hudi north of the Atbara and *in situ* at Zeidab on the west side of the Nile where they rest unconformably on the Nubian Series. They contain freshwater species of gastropods belonging to the genera *Pseudoceratodes*, *Pila*, *Planorbis*, etc.

The Tertiary period is chiefly marked in the Sudan by vulcanicity of the East African type^{23 3135}. In the eastern parts between Berber and Suakim there are many volcanic craters with masses of lava and scoriae pierced by dyke-rocks. From Gule southwards to Keili, at the foot of the Abyssinian highlands, there are younger volcanic rocks and some hills with craters. In the Bayuda desert between Berber and Merowe there are fresh-looking cinder- and lava-cones, while in Kordofan^{2 16} and the Libyan Desert many

extinct volcanic hills have been discovered. In Darfur^{21 38} there is a volcanic centre in Jebel Marra^{3 9 38} with one extinct volcanic mountain, Dereiba, 10,000 ft. high, having a lake in its crater. Soda-trachyte rocks, riebeckite-trachyte, kenyte, and mugearite here occur much like those in East Africa.

The period of eruptivity is uncertain, but from the evidence in Kenya it may be conjectured to have lasted for a long time, probably from early Tertiary. North of Jebel Marra there is the large Malha explosion crater^{9 11} in the Meidab Hills, rising to a height of 3000 ft. and breaking through the Nubian Series. Lava fields in this region also extend over wide areas. In the Uweinat district^{16 28 30 34 4 1 4 4 49} there are volcanic hills and craters scattered over many miles and often highly conspicuous, though much reduced by denudation. Trachytic and phonolitic lavas are the chief types, and thick sheets of lava cap many of the hills, while some of the explosion-craters S.W. and N.E. of Uweinat have plugs of trachyte. But olivine basalts occur at Malha and in some other places.

The isolated hill of volcanic origin known as Ahmed Aga,¹ about 100 miles north of Fashoda, consists of basaltic scoriae and limburgite, and is believed to be of Oligocene age, as are those farther north in Egypt, where the igneous rocks pierce Cretaceous and Eocene beds.

Post-Tertiary Deposits.—Lateritic deposits occur in patches on the older rocks. But the chief superficial deposits are æolian, constituting the immense areas of sand dunes in the western desert^{20 22}.

The igneous gravels of the Red Sea hills, which are largely developed along the coast of Egypt farther north, form terraces and hills also on the coastal plain in the Sudan. The Raised beaches and coral reefs along the sea-coast southwards of Somaliland are of late Pliocene or Pleistocene age and contain a rich molluscan fauna^{21 40 40a 50} mostly of living species, and mark recent changes in the sea-level²¹.

The river terraces along the Nile are of Pliocene and Pleistocene age with their human artefacts, and have been the subject of a recent treatise by Sandford and Arkell⁴⁶.

The black 'Cotton soil,' which covers large areas in the southern Sudan and spreads widely into adjoining parts of Uganda³⁹ and Kenya, is of the same nature and origin as the *regur* of India and is of recent formation.

Tectonic Features.—The chief folding movements took place at different stages prior to the deposition of the Palaeozoic beds, and thus affect only the rocks of the Basement complex. But other kinds of earth-movements, such as faulting and tilting, occurred before the Cretaceous Nubian Sandstone was deposited, and this sandstone was later itself affected by disturbances on a minor scale. But our knowledge of the tectonics of the Sudan is much less complete than of those of Egypt, and the Mio-Pliocene movements which influenced the Nile in Egypt^{37 41} have not been definitely traced. The curves in the course of the upper parts of the Nile in the northern Sudan are held to depend mainly on the folds in the older rocks, rather than on the lithological or structural character of the rocks themselves.

The physiography of the Nile Valley and its history have been described and discussed by many authors, especially by Lyons⁸⁸, Ball¹⁴, Hume¹⁷ Ardlit⁴⁷ Sandford³⁷, and Awad⁴¹.

Earth Movements of late Tertiary Time in the Red Sea Region.—Since Middle Pliocene times earth-movements of various types and degrees of magnitude have taken place in the Red Sea area. According to Hume it was during the Middle Pliocene that the

folding took place which determined the main physical characters of this region. The axes of the folds trend N.N.W. to S.S.E., and are parallel, but the folds are not symmetrical and the steeper wave-fronts are towards the Gulf of Suez, and overthrusts or overfolds towards the centre have been locally developed. The main folds are of the 'piercing' or 'diaper' type, wedges of the older granites, etc., being driven through the overlying younger and softer beds. The early transverse and longitudinal faults, between which the trough of the Red Sea has sunk, were formed in several stages in the same general period and are connected intimately with the great fault systems of East Africa and Palestine. The invasion of the present Erythrean marine fauna into the Red Sea took place in consequence of these crustal subsidences, and the district has continued in an unstable condition till recent times, local uplifts and depressions of the coast-line being indicated by the raised coral-reefs and beaches. Barron²⁵ attributes the formation of the Red Sea and Gulf of Suez, and of the parallel bordering ranges, to earth-movements in the late Pliocene and early Pleistocene period, but Ball^{12 14} regards both the Gulf of Suez and the Nile Valley as due to erosion and not to faulting. Hume¹⁷ considers erosion to have been the principal factor in the development of the Nile Valley, subsequent to the formation of a syncline, the axis of which the river partly follows. The faults in the Nile Valley, which are more or less parallel to parts of the course of the river, as on the left bank at Qena and at the Aswan Cataract, belong to the Pliocene period, and seem to have been the cause of the change in the river's course in the latter region. The longitudinal section of the Nile^{36 41}, however, shows that it has not been a normally developed river, but that the present Nile System must include portions of river-systems of very different origin and date⁴¹. Recently it has been shown to be highly probable that both the section of the Nile above Korosko and the parallel section from Abu Hamed to Korti were determined by lines of crustal fracture, and that the upper portion of the Nile Valley has not suffered the late uplift which has caused the deepening of its bed in Egypt³⁷.

The occurrence of a group of extinct volcanoes in the Bayuda Desert, between Merowe and Berber, suggests that their eruption was connected with these dislocations, and probably with the same set of Tertiary movements as those which produced the rift valleys farther south on the African Continent, and which are marked by outbursts of volcanic activity. (See 'East Africa.')

ECONOMIC GEOLOGY

Iron.—In the Bahr-el Ghazal and Upper Nile large masses of iron-ore and ironstone are known to exist^{8 13}, and in the Tokar district massive specular iron has been found.

Chromite.—This mineral occurs in serpentine and allied rocks in the Kassala region²⁶.

Gold.—In the eastern Sudan and adjoining parts of Egypt and in the Nuba Hills there are auriferous veins in the old crystalline and igneous rocks⁸.

Water Supply.—The various sources of water in the north-western Sudan^{19 42 43 51} are chiefly in old crater-lakes or in superficial detrital deposits or basins in the Archaean rocks⁴².

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CHAPTER III

EAST AFRICA

SECTION I.—BRITISH SOMALILAND AND SOCOTRA

(A) BRITISH SOMALILAND ²⁹

General Characters.—This protectorate forms the southern shore of the Gulf of Aden, and has an area of about 68,000 square miles. A maritime plain, known as the Guban, stretches along the coast east and west of Berbera, and slopes inland gently upwards 300 to 400 ft. to the foot of the Maritime Ranges, which run east and west as ridges varying from 1000 to 3000 ft. in height. South of and behind them follows the so-called Inland Plain which ends abruptly about 35 miles inland at the foot of the precipitous escarpment of the Somaliland Plateau. This escarpment rises to heights of 5000-7000 ft., and appears from the north like a jagged mountain range which is known as the Golis Range. The plateau itself, which slopes gently to the south-east and is called the Ogo, occupies about three-fifths of the country.

Geological Structure^{1410 11}.—The step-like character of the country north of the plateau down to the sea-coast is apparently the result of a series of gigantic parallel faults¹⁰, leading to the production of a series of fault-scarps. Their formation seems due to the same set of movements as led to the subsidence of the Gulf of Aden. But there are other lines of faulting and, according to MacFadyen¹¹, the whole structure of British Somaliland is 'almost wholly determined by simple faulting, of which there are three main trends: (1) the Gulf of Aden trend, east-north-east; (2) the Red Sea trend^{30 31}, north-west; and (3) the East African trend, north. The most important is the regional faulting of the first trend, which is the cause of the down-faulted Gulf of Aden and the Guban country and the up-faulted Somaliland plateau. Second in importance is that of the Red Sea trend^{30 31}, which is responsible for the smaller fault features in the country. Less frequent and less important are the faults with the East African northerly trend. All three systems of faults are held to belong to the Tertiary period, except perhaps those of the Gulf of Aden.

There are few traces of folding of the beds *in* the area, except some of local extent and of small account. The most important and

widely developed rocks are crystalline, such as granites and gneisses, and on them rest with a great unconformity some pre-Jurassic grits, but the sedimentary beds are chiefly Jurassic and Tertiary limestones in a more or less horizontal position. Most of the same formations and rocks extend into French^{15 22 23 24 27} and Italian Somaliland and Eritrea, and the faunas from those areas have been there extensively studied.

DETAILS OF THE STRATIGRAPHY

Archaean.—The plateau itself consists of a great block of the Archaean or ancient crystalline rocks, mainly granites, gneisses, and amphibolites with micaceous and chloritic schists, pierced by dykes of pegmatite, diabase, and other intrusive rocks. It belongs to the great East African massif of ancient rocks. The more rugged peaks of the Maritime Ranges are outliers, often faulted blocks, of this Archaean mass. The petrological characters of some of these rocks have been described by Miss Raisin⁶.

Pre-Cambrian.—Near the coast south of Las Khoreh, south of the Aden fault, but north of the Al Hills, there is a series of slates, quartzites, sandstones and beds of limestone, known as the *Ind Ad Series*¹⁰, which represent more or less altered sediments, and these beds also occur on the Berbera-Hargeisa road¹¹. It is possible that this series corresponds to the Karagwe System of East Africa (see p. 47). It is invaded at the west end by a large intrusion of granite. The beds of the *Ind Ad Series* have a general strike of a few degrees west of north, and belts of synclines alternate with belts of high dip. The Jurassic beds rest on their upturned edges.

In the Gadabursi country on the Abyssinian frontier and elsewhere Parkinson^{17 25} and Hunt¹⁸ describe a group of epidiorites and hornblende-schists with later foliated granites, to which the name *Buramo Schists* has been applied; they include fine-grained gneisses and thin pegmatites. Quartz porphyries interbedded with para-schists occur in the Zeilah district which have suffered pressure at right angles to that of the *Buramo Schists*, and soda rhyolites are also recorded.

Pre-Jurassic.—Resting on these crystalline rocks are unfossiliferous purple grits, red sandstones, and conglomerates of ^{unknown}, but certainly pre-Jurassic, age. The so-called *Adigrat Sandstones*^{9 11} mostly outcropping in the western part of the country are seen in the Daghani and other sections to rest on the Archaean and Pre-Cambrian rocks, and to pass up conformably into the lowest fossiliferous Jurassic beds. Probably the formation represents part of the Karroo System of East and South Africa, and may correspond with the Duruma or other members of the 'Mazeras Group' (Krenkel) of Kenya (*q.v.*). In some places lava flows^{7 11} have been recorded at the base of the *Adigrat Series*. Some poorly-preserved mollusca have been found in some bands of limestone amongst the sandstones. MacFadyen refers the *Series* tentatively to Trias-Lias. In Abyssinia it directly underlies fossiliferous Jurassic beds and consists of multi-coloured sandstones and shales.

Jurassic.—The earliest richly fossiliferous rocks known in the country are of Middle Jurassic age. These are not folded or disturbed, except by faults, and lie horizontal. These Jurassic beds correspond to the so-called *Antalo beds* of Abyssinia, but do not afford such a complete succession. In the Italian sphere they have been extensively studied^{22 23 27}. In north-eastern British

Somaliland Barrington Brown has described¹⁰ a series of limestones and sandstones, 1850 ft. thick, resting on supposed Palaeozoic rocks and containing a rich fauna at one horizon of Bathonian-Bajocian age. Liassic beds have been found just over the frontier near Harar²⁴. But the Jurassic in the British sphere mostly belongs to higher stages.

At Bihendula, 20 miles south of Berbera at the foot of the plateau scarp, good section of Jurassic beds is exposed, and MacFadyen and Cox^{11 12}, who give a detailed account of the Daghani section of this Bihendula outcrop, recognise Callovian, Argovian, Kimeridgian, and Portlandian horizons. The beds consist of limestones and shales, and have yielded a rich fauna^{2 7 8}, which includes many foraminifera¹², corals¹⁴, echinoids¹³, brachiopods, and mollusca¹², including the Indian lamellibranch *Parallelodon* (*Indogrammatodon*) *egertonvanum* of the Spiti shales (see chapter on India) which occurs here in Argovian and Kimeridgian horizons. Many typical Jurassic ammonites have also been described by Spath¹². The extension of these beds into French and Italian areas with a similar fauna^{15 16 28} has further increased our knowledge of the fauna. The lower beds are stated to have a mixture of Indian and European species, but in the upper beds the Indian element has disappeared, and the fauna is that of western Europe.

Cretaceous.—Some fossiliferous Cretaceous limestones and marls in the Al Hills of Neocomian age and sandstones of Senonian age have been recognised by Barrington Brown¹⁰, and the fossil contents consisting chiefly of echinoids² and mollusca¹² have been described by Hawkins, Cox, and others. The Cretaceous fossils of the adjoining Italian Somaliland²⁷ have been described by Stefanini¹⁵, and his memoir supplements the papers above mentioned.

The stratigraphical reference of the unfossiliferous arenaceous beds of the Protectorate is difficult or only tentative in different parts of the area where their relation to fossiliferous horizons have not been established. But some are undoubtedly pre-Jurassic and others only pre-Cretaceous or even partly Cretaceous, the latter corresponding to the Nubian Sandstone (Nubian Series) of the Sudan, and it appears to have been deposited over most of the area and in the north-east to pass up into the definitely Cretaceous beds of Barrington Brown. This arenaceous series outcrops now chiefly around Hergeisa and east of Berbera¹¹, and consists of beds of brown, white, yellow, purple, or black sandstones with beds of shale rarely interbedded, and contains only silicified wood. In places its thickness varies, but it may reach 4000 ft. In the Guban it rests conformably on the uppermost Jurassic, but on the plateau it reposes directly on the Archæan rocks.

In a small area south of Dagah Shabell¹¹ there is a special and peculiar facies of the Cretaceous consisting of red micaceous clays, occasionally gypseous, alternating with current-bedded grits and sandstones with some interstitial salt in places. These beds, known as the *Shabell Beds*, are under- and over-lain by typical brown Nubian Sandstone.

Gregory¹ attributed certain limestones, the Dobar and Auradu limestones, which occur in the Maritime Ranges and on the summit of the plateau, to the Neocomian and Turonian. But Newton⁴ referred them both to the Middle Eocene (see below) on a revised identification of the fossils (see below). True Neocomian occurs, according to Mayer-Eymar⁵ and Dacque³, west of the British frontier between 40° and 41° E. long., and 7° and 8° N. lat., and also to the south below 6° N. lat. and near 45° E. long., and Dacque mentions the presence of *Exogyra couloni* of Lower Cretaceous age in a limestone in the interior.

Eocene.—Eocene beds comprising the Lower and Middle divisions^{11 12} cover much of the south-eastern part of the country.

In north-eastern Somaliland the Lower Eocene, according to Barrington Brown¹⁰, has yielded *Dictyonoides newboldi*, *Alveolina subpyrenaica*, *Linthia Somaliensis*, and other fossils. The Lower Eocene (*Auradu Series*)¹¹ elsewhere consists likewise of marine limestones and shales with many fossils¹².

The Middle Eocene (*Karkar Series*) in the same region consists of the so-called *Anhydrite Series* followed by a series of thin-bedded chalky limestones and shales containing *Nummulites discorbinus* and many species of mollusca, including large gastropods such as *Gisortia*. The *Anhydrite Series*, which is absent in the west of the country, consists of nearly pure anhydrite 1000-1200 ft. thick, with thin inter bedded flaggy limestone crowded with echinoids of the group of *Sismondia polymorpha*. The scanty fauna has more affinity with the Middle Eocene (*Karkar Series*)¹¹ which is about 700 ft. thick and covers great areas in the east, north of the main outcrop of the *Anhydrite Series*. Many foraminifera²⁶ occur in the matrix, and include *Operculina complanata*, *Orbitoides dispansa*, *Amphistegina* sp. Among the corals^{14 15} in the *Auradu* limestone there are species of *Calamophyllia*, *Goniopora*, *Golumnastrea*, *Litharæa*. etc. The echinoid genus *Schizaster* is also found, and amongst the mollusca are the Egyptian Eocene forms *Spondylus egyptiacus*, *Lucina* cf. *thebaica*, and species of *Gryphæa*, *Delphinula*, *Solarium*, *Euspira*, etc.

The Upper Eocene may be represented by the *Duban Series*, of which there is a basin about 25 km. south-east of Berbera. It rests conformably on the *Anhydrite Series* and consists of shallow-water lacustrine deposits including thin limestones, shales and sandstones, with some anhydrite beds and gypseous clays. Freshwater shells, ostracods, fish-remains, and silicified wood are found in it. The series is of great thickness, reaching nearly 7000 ft. The uppermost, or so-called 'Nautilus beds', * are marine.

Miocene.—The *Dubar (Dobar) Series* of limestones^{10 11} in the Berbera district occurs in patches and isolated outcrops. It contains abundant foraminifera, especially *Miogyssina*^{11 12} and corals²⁴, and the fauna points to a Burdigalian age. It is doubtful if any Oligocene beds are present in British Somaliland, but it is possible that the upper part of the *Duban Series* belongs to it.

Pliocene to Recent.—The Pliocene¹⁰ and Pleistocene are represented by Raised beaches up to 600 ft. above sea-level and by the higher gravel and boulder beds²⁵ up to a height of 1800 ft. Two periods of erosion have been observed by MacFadyen: one after the accumulation of the boulder beds, and the other after that of the gravels, suggesting Pluvial periods. The Raised beaches contain marine mollusca^{19 20 20a} and range in age from Pliocene to Recent. The raised coral reefs²¹ occurring at heights of 8, 85, and 200 metres likewise are of more than one age, and yield faunas of their successive periods. The æolian sands and the marine magnetite and garnetiferous coastal sands are of Recent formation.

Volcanic Rocks^{6 17 11}.—There are two main areas of late volcanic outbursts in British Somaliland: the one south of Bulhar, where lava-flows of basalt form nearly flat plateaus, and the other consists of the Elmis volcano, which rises 1800 ft. above the maritime plain and consists of stratified tuffs and lavas cut by dykes, and much resembles the Aden volcano (*q.v.*). There are also red lavas and basalt flows along the Jibuti border; these are of Pliocene or Recent age, like the Arden Volcanic Series of Blandford. These eruptions may be correlated with those of East Africa. It seems that the volcanicity died out earlier in the south-east, lasting till Recent times in the north-west, and extending into Abyssinia. In French Somaliland the corresponding volcanic rocks and craters have been described by Dreyfus and others²⁸.

ECONOMIC GEOLOGY

Though minerals of economic value are known to occur, there has been no development of mining, and the search for petroleum has not met with much success.

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(B) SOCOTRA

Physical Characters.—The island of Socotra, which measures about 72 miles in length from east to west by 22 miles in width, has its coast bordered on the north and south by wide alluvial plains of recent origin, but the interior consists of a broad undulating plateau of limestone averaging 1000 ft. in height above sea-level, and surrounding on the west, south, and east a small nucleus of granitic mountains rising to a height of over 4600 ft. Two small islands, Semha and Abd-el-Kuri, lie on the submarine bank stretching westwards towards Cape Guardafui of the mainland.

General Geological Structure¹.—The geological structure is simple and resembles that of the neighbouring parts of Arabia and Africa, consisting of a mass of crystalline rocks with almost undisturbed Cretaceous and Tertiary beds resting on them. It is apparently a horst or fault-block separated off from the mainland by the same series of dislocations as were concerned in the production of the Gulf of Aden in late Tertiary times.

DETAILS OF THE FORMATIONS

Archæan.—The above-mentioned nucleus of ancient igneous and metamorphic rocks^{2,3} is exposed in the main *massif* of the Haggier Mountains near the north-east coast, and there are two smaller exposures of the same rocks at the east and west ends of the island. These ancient rocks are divisible into two groups⁶: (a) gneisses, generally granitoid, together with granites mostly of

a light reddish colour and pierced by veins of aplite and pegmatite, and in some places by small veins of melaphyre. (This group forms the highest peaks of the mountains); and (b) dark green amphibolite schists, such as are conspicuous in the Archaean series of East Africa. According to Kossmat¹ these are younger than the granites and dyke rocks which pierce them. Probably the intrusive rocks do not all belong to the same period. The small island of Abd-el-Kuri to the west of Socotra is composed entirely of these old rocks, both groups being represented, and kersantite and camptonite dykes have also been described on it. The basement rocks on Socotra resemble in every respect those of the East African massif, of which the island may be regarded as a severed fragment.

Cretaceous.—Resting on these crystalline rocks is a series of fossiliferous Cretaceous beds¹⁵ scarcely at all disturbed. The succession is best seen in the island of Semha, where the lowest beds consist of quartzose sandstones passing up into a succession of marls and fine sandstones containing *Ostrea* and *Modiola*, together with yellowish or brown rudistid limestones, which principally contain *Radiolites* and *Caprinidae*, *Hippurites* being very rare. These beds are referred to the Cenomanian.

Immediately above them comes a sandy marl also of Cenomanian or Turonian age with *Orbitolina plana* D'Arch., *Pecten (Janira) quinquecostata* Sow., *Exogyra flabellata* Goldf., *Placenticerus simonyi* Kossm., etc. These marls become chalky and pass up into white chalk which ends the Cretaceous series. On the island of Semha the chalky white limestone resting on the marls contains *Hemiaster* and other echinoids, together with *Terebratulula semiglobosa*¹.

The Cretaceous beds attain their maximum thickness of about 300 metres at the east end of Socotra¹. The whole facies of the fauna is Mediterranean.

Eocene.—The greater part of the plateau consists of Eocene limestones which occasionally repose directly on the Archaean basement. The beds are mostly white *Alveolina* and Nummulitic limestones² of a thickness of about 400 metres¹, and are almost horizontal and undisturbed, but a few weak folds are traceable trending W.N.W. to E.S.E., for these beds have suffered in the general gentle folding noticeable in the island. Fossils are rare, except the foraminifera. The alveolines mostly belong to the group *Alveolina oblonga* and *A. frumentiformis*. Small nummulites, *Operculina* sp. and *Orbitolites complanata* Lam., also occur, and layers of *Orbitoides*¹ are described. The limestones are of a compact massive character, and are in places coarsely crystalline⁶; the beds break off in steep cliffs along the coast and in the valleys.

Late Igneous Rocks.—According to Gregory^{4 6} and Forbes⁶ the limestones (or some of them) are pierced by dykes and masses of trachyte and basalt, and in the south-east of the island an eruption of trachytic or rhyolitic lavas^{1a} with associated agglomerates appears to have taken place; these resemble the Aden volcanic series rather than those of East Africa.

Late Tertiary or Recent conglomerates, grits, and breccias are found in the valleys and on the coastal plains which consist chiefly of recent alluvial deposits.

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SECTION II.—KENYA COLONY AND UGANDA PROTECTORATE

General Characters.—The whole of East Africa forms part of the great African mass^{39 120} of ancient rocks and a fragment of the former Gondwanaland. This great East African plateau^{40 42 75} of Archaean or Pre-Cambrian rocks on which the larger part of Kenya, Uganda, and Tanganyika rests, covers an area of over 500,000 sq. miles and has an altitude above present sea-level of 3000 to 6000 ft. In Kenya the long slope rises to the summit of the Aberdare Mountains in about 300 miles. The Kenya portion is divisible, according to Gregory³, into several more or less distinct geographical zones or areas ; and proceeding inland from the coast the following divisions have been recognised : (1) the coastal plain, mostly narrow and composed of a low-lying strip of land ; (2) the foot-hills, forming a narrow belt rising by a steep slope of 200 ft. to the west of Mombasa, but not everywhere present ; (3) the Nyika, consisting of wide plains elevated about 800 ft. above the coastal plain, and extending southwards from the Gulf of Aden to beyond the southern frontier ; (4) the primitive mountain axis of East Africa, rising through the Nyika or forming its western boundary, and represented by various ridges or chains of hills running north and south ; (5) the Rangatan, a zone composed of broad plains of volcanic rocks, such as the Kapiti Plains ; (6) a volcanic chain consisting of a meridional series of mountains with lofty volcanic cones (*e.g.* Mts. Kenya and Kilimanjaro) stretching down the middle of the Rangatan Plains ; (7) the highland zone, an elevated region interrupted by faults, and especially by the Great or Eastern Rift Valley, which holds many lakes and runs north and south. This zone extends westwards to the shores of the Victoria Nyanza. Farther to the west in Uganda we meet with the mountain mass of Ruwenzori projecting into the eastern side of the Second or Western Rift Valley, which holds the chain of great lakes ranging from Lake Tanganyika in the south to the source of the Nile in Lake Albert, and is continued far beyond it to the north and north-east. These rift valleys are among the most remarkable features on the earth's surface. (See below.) These valleys have been impressed on the more or less elevated and level surface of the plateau, which in different parts of the region has had a varied history and does not constitute one unbroken or uniform surface.

General Geological Structure³⁹¹²⁰.—There is a direct connection between the geological structure of the country and^{1 3 31 37} the geographical divisions above mentioned. The coastal plain, the foothills, and the Nyika are closely related to the three main groups of Palaeozoic and Mesozoic sedimentary strata which form what Maufe² has called the Coastal Belt. This belt reaches from the coast-line to mile 57 on the Uganda Railway². The fourth zone, called by Gregory³ the 'primitive mountain axis,' consists of a broad region of gneiss and ancient crystalline rocks stretching inland to the edge of the Kapiti and Athi Plains (mile 283 on the Uganda Railway), with here and there patches of later volcanic rocks. The remaining zones recognised by Gregory comprise a vast area mostly covered by volcanic rocks, and include all the central and much of the western parts of Kenya. In the highlands the area attains an altitude of 5000 ft. or more, and is traversed by the Eastern or Great Rift Valley^{42 75}, which forms a long narrow sunken strip of country or trench, reaching far to the north and south (see below), and strewn with numerous volcanic mountains along its course. In the Great or Eastern Rift³⁹ Valley the series of lakes, situated at various intervals along it, are separated by strips of the valley-floor which have not sunk to the same extent, the continuity of the depression being thus interrupted. Beginning in the northern part of Kenya we have Lake Rudolf, which is followed southwards after an interval by Lakes Hannington, Baringo, Nawasha, Nakuru, Magadi, and several others, down to the border of Tanganyika Territory, where the series continues. The 'grid-structure' of faults, as named by Gregory²², crossing the north-to-south line of the rift valley, has been one of the chief causes of the formation of this chain of lakes. Lake Victoria does not lie in the rift valley and has had a different origin, being only a wide saucer-like depression on the surface of the plateau occupying about 20,000 sq. miles with a depth of only 150-270 ft., and has been chiefly formed by the warping of the surface of the plateau, though faults on the west coast and in the Kavirondo Gulf influence its shape.

In several districts of the volcanic region old unfossiliferous sedimentary or crystalline rocks are exposed (*e.g.* Nandi). Round the shores of the Victoria Nyanza Miocene⁷ and Pliocene lacustrine deposits occur beneath the lavas (see below), but no marine deposits.

West of the Nyanza and embracing the line of great lakes in the Western Rift Valley^{42 44} the old Archaean or pre-Cambrian basement is again exposed in places with some ancient sedimentaries of doubtful but pre-Mesozoic and probably pre-Palaeozoic age (the Karagwe Series) resting on it, and it is considerably developed in Uganda.

In the Western Rift Valley, which describes a gentle curve convex to the west, we have at the north end in Uganda the Lake Albert Nyanza, which lies in a trough comprising the valley of the Albert Nile on the north-east and the lower valley of the Semliki River on the south-east⁷⁵. The depression occupied by the lake itself is a characteristic example of a rift valley^{39 42 72 75 109}. 'The sides are defined by faults which are arranged in two parallel systems, each system consisting of a number of displacements, offset *en echelon* along the strike.' The trough is about 115 miles in length, with a width of 22 to 28 miles. In depth it is shallow, being at its maximum only 25 fathoms in the middle, but it somewhat deepens towards its northern end. The sediments which occur in the Albert Edward range from Miocene to Recent; the bed-rock is Pre-Cambrian. The fault or faults along the south-east side form a steep escarpment traceable for 140 miles. Mt. Ruwenzori blocks its southern end. To the south of Mt. Ruwenzori the Western Rift Valley is continued and holds Lakes Edward and George, beyond which is the volcanic Bufumbira or Birunga chain of mountains cutting off Lake Kivu¹⁵³, which is in the Belgian Congo, while farther to the south in Tanganyika lies Lake Tanganyika. (See Tanganyika Territory). But Bailey Willis⁷⁵ regards the eastern and western escarpments bounding the southern end of the Lake Edward-George basin not as fault scarps of the rift type but as eroded slopes, the original valley being probably of the nature of a downwarp. But he states that the western side of Lake Edward is marked by a straight abrupt escarpment which is a true fault-scarp.

The many problems connected with the formation of the Rift Valleys have been discussed in great detail by Bailey Willis⁷⁵, who has made a special study of their structure and origin. Rival theories (see below) exist as to their formation, of which the principal ones are those of Gregory⁴² and Bailey Willis⁷⁵, but Wayland^{44 58 73 77 123} has also advanced his views on the subject, and Krenkel^{40 142}, Cloos¹⁵⁶, and others^{47 153 158} have discussed the whole question. The climatic changes¹⁶² in East Africa have greatly affected the development and history of the lakes in the rift valleys, and the succession of events has been studied and variously interpreted by Fuchs^{45 79 84}, Bowen⁶⁸, Leakey^{109 137 144}, Worthington⁹¹, Nilsson^{59 89 105}, and Kent¹⁰⁶.

The leading geological features of the whole area are the universal basement of Archaean and crystalline rocks, the marginal strip of sedimentary beds, the enormous and widespread development of Tertiary volcanic rocks, and the existence of great meridional tectonic trenches⁷⁵ and numerous lines of fracture^{39 42 79 132} (For geological map of Uganda see reference 109.)

DETAILED DESCRIPTION OF THE FORMATIONS

Archaean and Pre-Cambrian^{51 93 120 126 131}.—The crystalline, metamorphic, and old igneous rocks cover something like two-thirds of the whole surface of East Africa, and may with every probability be considered as underlying the greater part of the remainder. The peculiar inliers or 'inselberge'^{34 75 86} which stand up in the midst of younger formations, and are common features in tropical Africa, are frequently present here. These residual hills⁷⁵ are of several types and modes of origin; some are the remnants of ancient heights which erosion has failed to remove (e.g. the Taita Hills) owing to the hardness or lithological character of the rocks or position of the block between streams; others are partly due to faulting and may rise up with precipitous sides and are usually bare; others are exposed masses of intrusive rocks. But they all form conspicuous objects on the peneplain. The predominant rock is gneiss², usually well foliated, and the hill ranges composed of it mostly trend in a direction parallel to the foliation, i.e. from north-north-west to south-south-east. 'One of the commonest varieties of gneiss is a pale rock consisting of a quartz-felspar mosaic speckled with flakes of black mica and hornblende.' Biotite schists also are conspicuous rocks, as in Tanganyika to the south³. No true granite or other intrusion, except veins of pegmatite, is found in the gneissic region². In some places (Voi to Taveta) limestone bands, altered to crystalline marble, are involved in the gneissic series^{2 32}. In the western parts of Kenya⁵¹, as well as in the Frontier Province^{41 70 86} to the north and around parts of Lake Victoria^{93 107}, there is a wide development of the basement rocks, Archaean and Pre-Cambrian, with a great variety of petrological characters. In the associated intrusive igneous rocks gold is found, as in the Kakamega district⁶⁷ (see 'Economic Geology'). The stratigraphy of the Archaean and Pre-Cambrian rocks in the region of the Great Lakes has been summarised by Poussin¹⁵⁴.

The Archaean in the *Mt. Elgon* district is composed of a great variety of gneiss-granites, gneisses, amphibolites, schists, and quartzites. Pegmatites occur locally, and amphibolites form insignificant bands and layers. Characteristic of the formation is the northerly strike and flat dips, though locally the dip may be very steep and the rocks intensely folded. The quartzites represent a true sediment.

The separation of the Pre-Cambrian from the Archaean in Kenya and Uganda has not everywhere been worked out, so that the reference and correlation of several local groups of rocks cannot yet be decided. Thus on the northern frontier of Kenya^{70 71 86} and in the Kavirondo area⁶⁸, as well as on Ruwenzori^{117 118 119}, there are series of rocks which may be either Archaean or Pre-Cambrian, the correlation of the various series being a matter of opinion, and distinctive names for the local series are consequently in use. But the Pre-Cambrian rocks are everywhere separated from the basement Archaean by a great unconformity, though later earth-movements often obscure their relations. No fossils have been found in them, only ripple-marks. Sun-cracks and current-bedding occur. Their degree of metamorphism varies widely, some being scarcely altered sedimentaries or igneous rocks, while others have become schists or gneisses.

On the *Turoka River* south of the Kapiti plains there is a great series of metamorphosed arenaceous and calcareous sediments including marble-beds, scapolite-garnet schists, kyanite schists, and biotite-gneisses, which have been termed the *Turoka Series*^{5 26 41 62}. These are specially developed near Lake Magadi, but similar rocks also occur in the northern frontier districts and in Jubaland²⁴ under different local names. These are probably all of Pre-Cambrian age and later than the basement Archaean.

The gneisses and schists of the *Suk Hills* region in the north-western corner of Kenya have been described by Glenday and Parkinson⁸². The schists consist of a series of metamorphosed sediments and contemporaneous ashes closely resembling the *Turoka Series* south of Marsabit. The gneisses are intrusive into them. In the northern *Suk Hills*⁷¹ the *Kateruk Series* of metamorphosed sediments—sandstones, argillaceous silts, limestones, and probably ashes and lavas—are also closely related to the *Turoka Series*, but may be rather younger. Much altered gabbros and other basic rocks have invaded them. In the *Nandi* escarpment^{4 17 51} gneisses, highly sheared, together with mylonites, are found. At the *Broderick Falls* the lavas and clastic deposits are present, but the sediments have been converted into sericite quartzites and banded schists, while the intrusive granites become micaceous gneisses.

In the *Kavirondo* division^{15 31 56 67} the Pre-Cambrian is separated from the Archaean and is known as the *Muva-Ankole* System. It is a metamorphic series of sedimentary beds which are here invaded by the *Maragoli* granite mass extending westwards to Lake Victoria. Other igneous rocks are also intrusive in them, including later granites and basic dykes. Similar rocks spread into Uganda. In the North *Kavirondo* area⁶³ the Pre-Cambrian rocks are almost unaltered and consist of a lava formation followed by a thick series of clastic rocks. The lavas are of a basaltic character in the south, as at *Yala*, followed on the north by more acid types. The acid lavas with which tuffs are associated occur in the *Alego* Country, are more or less altered, and belong to the quartz-porphyritic group. The clastic rocks of Pre-Cambrian age comprise conglomerates containing pebbles of the lavas and also of granites and shales, phyllites, arkoses and greywackes.

Uganda is almost entirely occupied by gneiss and granite, but on the Nile, about *Dufile* and down the river as far as *Lado*, Pre-Cambrian altered sedimentary rocks, such as quartzites, quartz-schists, mica schists, and microcline gneiss, form the country, the metamorphic series striking nearly persistently N.W.-S.E.²³. A *Charnockite Series*⁶⁰, similar to that in India, including acid, intermediate, basic, and ultrabasic types, is developed in various parts of Uganda, but chiefly in the north^{44 59 62 72 81 93 94}, and *Groves*⁶² has described several types of these rocks between *Masindi* and *Butiaba*.

In the *Ruwenzori*^{98 109} massif and *Iveti* Mountains *Gregory*⁴ recognised a lower group of rocks composed of gneisses, and an upper group abounding in hornblende-schists, but also including mica- and chlorite-schists. Epidiorites and syenites are found associated with the lower group and banded amphibolites are conspicuous members of the upper group. Mount *Ruwenzori*^{4 72 75 95} is not a horst but an upraised mass consisting of a core of intrusive diorite, amphibolite and amphibolite-schist surrounded by metamorphic schists having their schistosity parallel to the rounded form of the intrusion; *Baily Willis*⁷⁶ holds that its uplift is due not to faulting but to 'local updoming,' step-faulting round its margins being inconspicuous and of minor effect. *Michot*^{98 117 118 119} has given a somewhat different interpretation of the structure of *Ruwenzori*, and has recognised '*nappes de charriage*' of Pre-Cambrian schists along the western flanks of the mountain mass connected with an arc of the same nappes in the Belgian Congo. The northern part¹¹⁹ consists mainly of basement gneiss and intrusive granite and serpentine.

In Uganda^{48 126}, as well as in the region extending southwards to Lake *Tanganyika*, similar rocks are much developed. In the district of *Chua*, northern Uganda, the older gneiss and granite are succeeded discordantly by mica-schists and quartzites which are folded into a synclinal^{126 126a} and have been termed the *Omoro Series*. The petrological characters of some of the old basement rocks (gneisses, amphibolites, etc.) in the district of *Chua* (Uganda) have been described by *Kazmitcheff*^{126a}. On the Sudan-Uganda

frontier⁴⁸, in the Langia-Acholi mountain region, gneisses and syenite, with a few basaltic dykes, occupy most of the area, but in the Mongalla-Rejaf area the parallel dykes of basalt are a marked feature. From their occurrence in the Karagwe district⁴ the Pre-Cambrian beds have been termed the 'Karagwe Series.' It is possible that the great series of lithologically similar beds in the Upper Congo Basin may be of the same age^{8 9}. It has been conjectured¹⁷ that part of the Karagwe Series may be referred to the Cape System of South Africa, and may be compared with the Cuddapah Series of India. But part may be older, and at any rate they are of pre-Karoo age. The rocks occupy almost the whole of Karagwe, Ankole, and Koki, and were divided by Gregory⁴ into four main successive groups, i.e. (1) granular quartzite; (2) coarse schistose sandstone; (3) red and brown sandstones, containing beds of haematite; (4) argillaceous beds, ranging from shales to well-cleaved killas. The rocks are of great thickness, but are much contorted and occasionally crushed and altered, and dip at a high angle⁴. These Pre-Cambrian rocks are specially developed in Ankole¹¹⁴ and Karagwe¹⁶¹ so that the series is frequently now termed the *Karagwe* or *Muva-Ankolean Series*. The northern or Bunyoro facies of this series has near its base a tillite⁹⁴ consisting of a hard fissile shale containing rounded, sub-angular or angular fragments of granite, quartzite, phyllite, mica-schist, etc., indicating a glacial epoch. A very fine banding in the altered silts which is characteristic suggests that they are varved sediments. The total thickness of the Karagwe-Ankolean Series varies from place to place, but ranges from 20,000 to 40,000 ft. In the adjoining province of Ruanda¹³² the equivalent of the Karagwe (Muva Ankolean) formation is termed by the Belgian geologists 'Système de l'Urundi,' while the older gneissic Archaean is known as 'Système de Ruzizi.'

The quartzitic sandstones of the Kisii Highlands⁷ have not been subjected to the pressure which has tilted up the Karagwe beds and dip at low angles west-south-west. In this region, according to Oswald⁷, the lowest part of the Karagwe Series is a quartz-porphry, the middle consists of schists, and the upper of the above-mentioned quartzitic sandstone, which he suggests is probably of the same age as the Waterberg Sandstone of the Transvaal, as Studt has maintained, but possibly is referable to the Transvaal System.* The ferruginous schists, shales, and phyllites from Unyoro are stated to bear a remarkable resemblance to Hatch's 'Hospital Hill Series' (Witwatersrand System) of the southern Transvaal,* according to Prior¹⁷. Further remarks are made on the pre-Karoo rocks in describing the Tanganyika Territory (see p. 76-77) into which all these series appear to extend.

Permo-Carboniferous and Triassic (Karoo System).—The occurrence of shales in the Sabaki Valley (lat. 30° 3' S. and long. 39° 5' E.), north of Mombasa, containing fossils of Permo-Carboniferous age, has been recorded by Gregory. These beds are not known on the Uganda Railway, except near Entebbe (see below), but south of the old British frontier in the Tanganyika Territory (*q.v.*) fossiliferous rocks of this period are better developed, and represent portions of the great Karoo System of South Africa.*

In the Sabaki Shales there has been recognised the lamellibranch *Palaeo-donta fischeri* (Amal.)⁷⁴ which is known from the Permian of the Oka-Volga Basin. Fish-scales also occur.

The Nyika region of Kenya is composed of a thick series of grits and sandstones, with subordinate shales, dipping gently towards the coast, and these beds are collectively known as the '*Duruma Sandstones*.' This belt of rocks, which runs roughly parallel to the coast, is about 45 miles broad where crossed

* See 'Union of South Africa.'

by the Uganda Railway. Southwards these beds form the Shimba Hills, and are continued behind Tanga, and probably form a nearly continuous border to the eastern edge of the gneissic region as far south as Lake Nyasa.* The lowest beds in the series occur on the Taru steppe, and are grits (*Taru grits*), massive, current-bedded and felspathic in character, and contain pebbles of pegmatite. Some micaceous shales with obscure plant-remains have been found in them, and they may be of Permo-Carboniferous age.

Overlying these Taru grits are alternating greenish mudstones and hard calcareous sandstones, the former sometimes with carbonaceous specks and the latter with plant-remains (*Thuyites* and *Carpolites*) and *Estheria*. Fine-grained yellow or white sandstones (*Mazeras Sandstones*), interstratified with sandy micaceous shales, succeed them, and finally there occur white sandstones with bright green marls and purple bands intercalated, ending with coarse-grained reddish sandstones with prostrate silicified tree trunks (*Cedroxylon*). Krenkel^{31 39} terms the whole series the '*Mazeras Group*,' and on petrographical grounds divides it into four sub-groups, regarding the whole as equivalent to the Karroo System of South Africa. The classification and nomenclature of these beds in the Nyika region has been revised recently^{56 74 97} and they are held to embrace deposits ranging from Permian to Rhaetic.

Mackinnon Wood⁹⁷ recognises the following beds in the Duruma Sandstone Series:—

? Trias	{ Shimba Grit.
	{ Mazeras Sandstone.
	{ Mariakani Sands.
Trias	Maji-va-Chumvi beds.
Permian	Taru Grits.

The above-mentioned fossil *Palæanodonta fischeri*⁷⁴ occurs in the Taru Grits and marks an Upper Permian age. The Triassic plant-remains come from the Maji-va-Chumvi beds. The Mazeras Sandstone has yielded specimens of *Dadoxylon*, and this may also indicate Trias. The Shimba Grit, which has so far yielded no fossils, was formed under desert conditions, as proved by the well-rounded grains of sand and by the polished and faceted pebbles contained in it.

In Uganda the *Entebbe Series*, which consists of freshwater deposits comprising black shales, with small seams of coal and some sandstones on the Jinja-Tororo road, have yielded some plant remains⁸⁶, and in a boring measured about 600 ft. in thickness. The plant-remains have been identified as *Gangamopteris* and *Cyclopteris*⁸⁵, which point to the Ecce horizon of the Lower Karroo System of South Africa and with the Lower Gondwana (Permian) of India. In the Walikale area, N.W. of Kivu in the Belgian Congo, the flora of the same *Gangamopteris* horizon has been found¹⁴⁵.

In the north-eastern extremity of the Northern Frontier Province of Kenya there are elongated horsts of a sandstone termed the *Marehan Sandstone*⁷⁰, which is correlated with the Duruma Sandstone Series of the coast. It lies below the Jurassic limestones and shales which cover a wide area.

Jurassic.—Overlying the Duruma Sandstones without any apparent unconformity there is a series of Jurassic beds including the '*Changamwe Shales*'^{31 38} of marine origin. These are exposed on the Uganda Railway from mile 9 to mile 11/6, where they pass down into the Duruma Sandstones. They consist of green to purple friable shales containing nodules of clay-ironstone and argillaceous limestone, and on one horizon there are large

* See description of 'Tanganyika Territory.'

boulders of coarse grit lithologically similar to parts of the underlying Duruma Sandstones. These beds have yielded a large number of ammonites^{86 74 82 97} of Upper Jurassic age. The fauna¹⁰⁸ includes several species known from the Katrol Sandstone of Cutch in India, which is usually correlated with the Upper Oxfordian and Kimeridgian of Europe. The presence of the Tithonian Stage seems questionable³², but a limestone in the Sabaki Valley contains fossils suggesting a Portlandian age. The subdivision of the Jurassic beds in the coastal area of Kenya has been carried much farther by recent work^{56 74 97 108}, and the whole series is now considered to represent horizons ranging from the Upper Lias or Bajocian to the Kimeridgian or Portlandian. The lowest Jurassic beds in this area are known as the *Kambe Limestones*, and are of Bajocian or Bathonian age, containing typical ammonites and brachiopods, and there are also Corallian limestones and Callovian shales. All these Jurassic beds, which have received local names⁹⁷, occupy the foot-plateau between the higher ground of the Duruma sandstones and the Tertiary deposits of the coast. (For the various classifications of the strata the paper by Mayer-Gurr⁹⁰ may be consulted.) Mackinnon Wood⁹⁷ gives the latest classification and correlation of the beds :—

Changamwe Shales	(Kimeridgian).
Corva Mombasa and other Limestones	Kimeridgian—Corallian.
Rabai Shale	Corallian—Oxfordian.
Miritini Shale	Callovian.
Kibiongoni	? Callovian.
Kambe Limestones and Mwachi Shale	Bathonian and Bajocian.

Amongst the fossils collected near Mombasa are the following^{12 13 108} :—*Aspidoceras loyigispinum* Sow., *A. iphiceroides* Waag., *Waagenia hildebrandti* Beyr., *Perisphinctes pottingeri* Waag., *P. beyrichi* Futt., *P. pralairi* Favre, *LytoGeras* cf. *montanum* Opp., *Oppelia trachynota* Opp., *Phylloceras* cf. *silesiacum* Opp., *Nautilus* aff. *hexagonus* Sow., *Belemnites* cf. *semisulcatus* Munst. The Oxfordian is represented at Port Reitz on the mainland opposite Mombasa by beds containing species of *Perisphinctes*^{90 97}. The Argovian fossil *Orammatodon egeronianus* (Stol.) of the Spiti Shales has also been found in the highest Jurassic.

Jurassic beds of the same and earlier horizons³⁹ have been recognised south of the old British frontier, and numerous fossils have been described from them^{10 11*}. Everywhere the fauna has strong Indian characters, but it also possesses some European and peculiar elements sufficient to constitute a distinct Ethiopian province³².

In the northern frontier district of Kenya and Jubaland Province⁸² the coastal belt of sediments is of Upper Oxfordian age, and some shales have yielded crushed ammonites at Kukatta on the Juba River^{24 41}. The Jurassic beds continue north and west⁷⁰ of the Juba River up the east coast of Italian Somaliland and contain a fauna^{82 136} similar to that in British Somaliland and Kenya. Some of the beds may belong to the Lias¹³⁶.

Cretaceous.—The occurrence of Cretaceous beds at Freretown near Mombasa is apparently indicated by the discovery of the following fossils¹³ : *Exogyra* cf. *aquila* Brong., *Ostrea macroptera* Sow., and *O. minos* Coq. The two last occur in Europe in the Neocomian, and the *Exogyra* in the Aptian. But Maufe says that no palæontological evidence exists for the belief that Cretaceous rocks occur on the line of the Uganda Railway²⁵. Farther south in the Tanganyika Territory (see below), Lower Cretaceous beds are largely developed, and possess a fauna showing affinities with those of Cutch and South Africa. The

* See description of 'Tanganyika Territory.'

Tendaguru beds of Jurassic-Cretaceous age with their huge Dinosaurian remains have not yet been recognised in the Kenya area, nor do the Lower Cretaceous (Uitenhage) beds nor the Upper Cretaceous (Makonde) beds of Rufiji extend apparently northwards from the Tanganyika Territory into Kenya.

Eocene.—The Eocene nummulitic limestones which are found near the coast farther south in the Tanganyika Territory between Kilwa and Lindi¹⁰, are not developed to the same extent in Kenya. But the presence of marine Eocene deposits on the coast between the rivers Tana and Sabaki at a height of 80 metres is signified by a coral *Favia somaliensis* and a gastropod *Volutilithes* of. *sanarensis*.

Miocene¹⁰⁴.—Marine Lower Miocene limestones of Aquitanian-Burdigalian age containing abundant mollusca^{56 74 97} and some echinoids with the faunistic facies of the contemporaneous beds in Madagascar, Persia, and India have been described by Cox from near Gushi south of the Sabaki River and near Punda Isa north of that river on the coast, as well as from the island of Pemba⁵⁴ (see 'Zanzibar and Pemba').

Beds of fresh-water and terrestrial origin, the *Karungu Beds*^{7 104 134}, are found beneath the lavas on the eastern shore of the Victoria Nyanza and resting directly on the Archaean gneisses and amphibolites. They consist of clays, shales, marlstones, and conglomerates to a total thickness of about 155 ft., and contain terrestrial and fresh-water mollusca of existing species with bones of *Dinotherium*, anthracotheroids (*Merycops*), a hyracoid (*Myohyrax*), a carnivore (*Pseudcelurus*), chelonians, etc. The fossils indicate a Lower Miocene (Burdigalian) age^{42 104 134 138 149}. These beds appear to have been deposited in a lagoon in which calcareous springs acted intermittently, and fall, broadly speaking, into three groups, but without any discontinuity or unconformity: (1) an upper series (average thickness, 70 ft.) of grey and brown clays, containing very few fossils; (2) a middle series (average thickness, 30 ft.) of variable red and grey clays with white sandstones in the lower half; and (3) a lower series (average thickness, 55 ft.) of buff-coloured sandstones and torrential gravels (containing the *Dinotherium* zone), passing down (at Nira) into clays and marlstones. The upper series contains a few land and fresh-water shells and calcified tree trunks. The middle series yields a few shells and Chelonian and crocodile remains and the hyracoid *Miohyrax*. In the lower series the *Dinotherium* and various anthracotheroids and other mammals are found, including several genera of Primates¹⁴⁹. These Miocene beds near the Kavirondo Gulf^{107 134} of Victoria Nyanza lie in an east-and-west rift valley formed before their deposition, and they are typically shown on Rusinga Island¹³⁴, where the fossiliferous clays and sandstones, forming an Argillaceous Series, rest on a basal agglomerate and pass up through a Tuffaceous Series to interbedded tuffs and agglomerates on which rests a nephelinite lava. After consolidation the beds suffered much faulting, some folding and shearing and, finally, were intruded by numerous dykes. This Miocene lake is considered to have been produced by local earth movements and not by the broad warping which produced Lake Victoria, which is of post-Pliocene age. It is remarkable that, although all the mammals are ancient and of Miocene, or even Oligocene, types, all the mollusca found at Karungu belong to living species¹³⁴. Bailey Willis⁷⁵ held that the Karungu beds were Pliocene fluviatile deposits and that the Miocene vertebrate remains were derived.

On the west side of Lake Rudolf^{84 101 108 152} in the Turkana there is a series of tuffs, grits, and conglomerates 100 metres thick interstratified at the base of the basaltic lavas^{84 150}, which partly constitute Mt. Losodok, and in these beds there occur plant-remains and mammalian remains

comprising *Mastodon*, *Pliohyrax*, *Aceratherium*?, *Listriodon*, *Brachyodus*, *Dorcatherium*, etc., indicating a Lower Miocene age⁷⁸. The strata dip at about 15° to the E.N.E. and are covered by an important series of ancient lake terraces. The mammalia and other vertebrates from all these East African Miocene deposits have been described by Andrews¹³⁸, Hopwood^{52 149}, and Arambourg⁷⁸. It may be mentioned that *Haug* (*Traitde Geologic*, 1908-11, vol. ii., p. 1727) regarded the Omo River deposits north of Lake Rudolf, which have yielded a non-marine molluscan fauna with *Dinoiherium*, as being of Pontian or Upper Miocene age²⁴.

Wayland⁴⁴ has recently described the Tertiary strata which accumulated in the Albertine depression of the Great Rift Valley. They comprise shallow-water sediments of Miocene, Pliocene, and Pleistocene age, divisible into two formations separated by an unconformity, and they dip gently to the north-east, with low folds running parallel to the walls of the rift. They are of importance in connection with the occurrence of oil⁹⁵. The lower beds⁵ at the south end of Lake Albert, consisting largely of arenaceous deposits with some conglomerates, are known as the *Kisegi beds* and are of Miocene or Oligocene age. Resting on them unconformably are the *Kaiso beds* (see below).

Pliocene and Pleistocene^{58 74 97 122}.—The presence of marine Pliocene deposits near the coast has been recently proved, since the so-called *North Mombasa Sands*^{56 74 97}, termed by Krenkel^{2 31} the 'Makupa Sandstones,' contain, on Mombasa Island, an abundant fauna of mollusca, etc., which show a close relationship to certain Pliocene beds on Zanzibar⁵⁴ (q.v.) The red sands on the mainland near Magarini, and called the **Magarini Sands*,' may also be of Pliocene age, but the fossil evidence is insufficient. In north-eastern Uganda there is a sandstone, known as the *Bugishu Sandstone*, resting on a peneplain of Miocene or Pliocene age⁸⁰. It contains fossil plants⁶¹ (leaves, fruit, and wood) with a modern aspect, for all the species show a relationship with living forms, and three of the genera are especially characteristic of the existing forests in East Africa. The Bugishu Series⁸¹, near Mt. Elgon^{76 127}, has been divided into two main groups—a lower or sedimentary group, and an upper or volcanic group⁷⁶—but some lava-flows (nephelinites) are interbedded in places with the sandstones, quartzitic grits, limestones, conglomerates, and agglomerates. The sediments were deposited in a series of lakes around the mountain.

The occurrence of fresh-water limestones^{24 41}, calcareous sandstones, etc., in the northern part of Kenya, containing a molluscan fauna somewhat resembling that found in Pliocene lacustrine beds near Lake Assal in French Somaliland, has led to the belief that a large fresh-water lake existed in this region in Pliocene times.

On the eastern shore of the Victoria Nyanza, near Homa Mountain^{7 128 163} there occurs a white calcareous travertine, overlaid by greyish clay and sandstone of lacustrine origin, containing the bones of *Elephas* aff. *meridionalis*, *Hippopotamus*, *Phacochcerus*, and antelope. The beds¹⁶⁴ are thrown into a broad syncline, probably due to a local subsidence. In the Lake Albert depression beds with a similar fauna have been described by Wayland, L. R. Cox, and others⁷⁸. These are called the *Kaiso beds*^{23 79}, which dip only from 5° to 10° and consist chiefly of argillaceous deposits with some sands and sandstones, beneath which ironstones associated with gypsiferous clays occur. The ironstone horizons yield fossils, comprising fishes, reptiles, mammals, and shallow-water mollusca. Many of the species are extinct, but, on the whole, the fauna broadly resembles that living in the Albertine area to-day⁷², and the beds are considered to be of Pliocene or **early** Pleistocene age¹²². The character, relations and age of the fossil mammalian faunas from the Tertiary beds of

Kenya and Uganda have been discussed by Hopwood^{52 128 151}, and those from beds near Lake Naivasha more recently by Lonnberg⁶⁵. At the Gaza water-hole⁸⁴ in the Northern Frontier province a fossiliferous horizon containing lacustrine mollusca of Nilotic species has been found underlying basaltic lava flows. Two of the species occur also in the Kaiso beds with which this deposit may be correlated.

The Omo beds north of Lake Rudolf, from which Arambourg⁷⁸ described mammalian remains, are considered by Fuchs¹⁵² to be on the same horizon as the Kaiso beds. In the Lake Edward⁷⁹ basin the lacustrine beds are of the same age as the Kaiso Series of Lake Albert; the climate became increasingly arid during their deposition, for towards the top of the series are gypsiferous clays and deposits of *kunkar* (limestone concretions in clays or sands) and frequent bands of ironstone, sometimes oolitic⁷⁹. The fauna includes mammalia, crocodiles, and turtles, fish and mollusca. After the deposition of these beds faulting took place. But subsequent to these movements precipitation was renewed and another shallow lake was formed holding a different fauna⁷⁹, like that in the Uganda lakes⁹¹. To the east and north of Lake Edward Kaiso deposits also accumulated, and similar deposits with molluscan remains are found near the source of the Semliki on the west of the lake⁹⁹. Old river deposits of the Second Pluvial period (*Gamblian*) occur as gravels in the Lake Edward basin, resting on the Kaiso Series⁷⁹, and the Kaiso deposits as well as the Gamblian are also found in the Kazinga Channel connecting Lakes Edward and George.

It is a suggestive fact that the Pleistocene beds around Lake Edward have yielded extinct species of mollusca⁶⁶ resembling those now living in Lake Tanganyika²⁰ (*q.v.*), in which the molluscan fauna has peculiar halolimnic characters²⁰, much like certain Jurassic marine mollusca, but of disputed origin.

Marine Pleistocene.—Along the sea-coast of Kenya there are also Pleistocene and Recent deposits of some extent²⁵. For instance, the Pleistocene formations on Mombasa Island consist of the ' *Kilindini Sands*' and sandstones yielding a fauna similar to that of the raised coral-reef 40-80 ft. above sea-level, the fossils belonging mostly to well-known Recent species in the Indian Ocean. There are also isolated Recent or Pleistocene oyster-beds in several of the river-valleys of Kenya, which point to recent elevation of the coast or local inroads of the sea. The peculiar molluscan fauna found in the Pleistocene beds of Lake Edward is thought by Fuchs¹⁵⁷ to show a marked resemblance to the so-called halolimnic mollusca now living in Lake Tanganyika, and thought by Moore to possess Jurassic affinities and to indicate a Mesozoic invasion of the sea.

Volcanic Rocks of Pre-Tertiary, Tertiary and Recent Age^{53 57 62 64 68 76 88 89}

112 135—Volcanic rocks are spread over all the central and much of the western parts of the East Africa Protectorate, covering an area of about 24,000 sq. miles south of lat. 1° N., and including all the highlands at altitudes of 5000 ft. or more. In the Northern Frontier district and in western Jubaland lavas are widely spread, and a line of lava escarpments runs northwards from the Uasa Nyiro to the volcano of Marsabit⁴¹ with its crater lake, while at the south end of Lake Rudolf⁸⁴ rises the volcanic cone of Mount Teleki^{101 112}. The Great Rift Valley which traverses the volcanic area from north to south has the Mau fault-escarpment of volcanic rocks forming its western wall on the Uganda Railway and the Kikuyu escarpment of similar rocks on its eastern side. The ground slopes away respectively to the east and west from the edges of these escarpments, and this is directly due to the fact that the volcanic beds on each side dip as a rule in these directions (though at a less angle than the average slope of the surface), thus forming a broad low arch of which the crown

has been broken, according to Gregory's theory⁴², and has then subsided along parallel lines of meridional faults resulting in the production of the Great Rift Valley with its marginal fault-scarps. (See p. 61.)

The volcanic rocks consist of various lavas⁶⁸, tuffs, ashes, agglomerates, and dykes, and occasionally contain interbedded sediments.

Two types of eruption may be recognised occurring more than once in successive periods of activity. The earlier lavas were poured out by fissure-eruptions and spread out in horizontal sheets over large areas. Several more or less distinct types of lava seem to have flowed out from different centres, but the prevailing type of lava in the Kapiti Plains is phonolite. These eruptions mostly took place prior to the subsidence which formed the Rift Valley, for the fault-scarps truncate the flows. Subsequent to these dislocations crater-eruptions took place on the floor of the Rift Valley (as near Magadi) and along its margin, as well as on the surface of the plateau, resulting in the production of many volcanic cones, some of which are much denuded, but others have their craters so perfect as to prove their late geological origin¹⁴⁰. Crocodile Island in Lake Rudolf consists of a group of craters occupied by lakes, and Crescent Island in Lake Naivasha is the rim of a half-submerged crater. The last stages of vulcanicity in the shape of fumaroles and hot springs which occur at various points are further evidence of the recent date of the volcanic eruptions in this region, and still active volcanoes are included in the Mfumbiro Mountains¹²⁵ in the Western Rift Valley outside the British Colony and in the Great Rift Valley south of Lake Natron.

East of the Great Rift Valley the volcanic rocks rest directly on the gneiss; but in the Victoria Nyanza region¹¹² the Miocene lacustrine rocks occur below flows of nepheline basalt⁷ (Naivashan stage of Gregory⁴²), while in the districts where the Pre-Cambrian Karagwe Series is the basement this group of ancient sedimentary deposits is interposed between the gneiss and the volcanic beds.

The period of volcanic activity in East Africa was undoubtedly of considerable length, and probably commenced in late Mesozoic times. Gregory⁴² believes that the oldest lavas were poured out in late Cretaceous times, and are perhaps contemporaneous with the Deccan Traps of India. But Kent¹⁸⁶ holds that none is of Cretaceous age. The breaking up of Gondwanaland led to the first volcanic eruptions along the sides of the sunken area which forms the Arabian Sea and Indian Ocean. This oldest series of lavas in East Africa Gregory calls the '*Kapitian Group*' because of its development on the Kapiti plains; it consists of phonolites of various types^{17 68} forming a, striking rock-series, and characterised by the amount and variety of soda-amphiboles as well as of soda-pyroxenes. Perhaps the old augite-andesites and agglomerates described by Oswald⁷ from the country between the Victoria Nyanza and the Kisii Highlands belong to this early phase of vulcanicity. According to Gregory⁴² the next series of igneous rocks in the volcanic succession composes what he terms the *Doinyan* Series which is marked by a lava termed 'kenyte,' from Mt. Kenya, which is typically formed of it. These rocks build up mountains instead of forming lava plains, and the older vent of Kilimanjaro consists of this type of rock. After a period of erosion and of earth-movement marking the first stage in the formation of the Rift Valley, lacustrine deposits were laid down in some localities (e.g. in the foothills of Kamasia), and these contain pebbles of the '*Kapitian*' lavas. Above these sediments, which are of Lower Miocene age, comes a series of basalts baking the clay-beds and resting on the denuded surface of the older lavas. Gregory calls this basaltic series the '*Laikipian*,' as it forms the main cap of Laikipia. Phonolitic trachytes and rhyolites are also included. Probably to this series belong the nepheline-basalts which directly overlie the fossiliferous Miocene beds of the Victoria Nyanza and further plateau-eruptions of phonolites. On

the Kedong scarp of the Eastern Rift Valley the trachyte lavas overlie the olivine basalts⁸⁸. It is probable that the nephelinites of Mount Elgon and the Nandi district belong to the succeeding period, which Gregory termed the *Naivashan* and ascribed to the Pliocene. It is represented by not only nephelinites, but also by comendites, and these compose the sub-Longonot ridge south of Naivasha. The Pleistocene and Pliocene eruptions are difficult to separate, but the volcanoes of Menengai, Suswa, and Longonot probably began to be formed in late Pliocene or early Pleistocene times and still show signs of activity. But Doinyo Ngai, near Lake Natron, and the Teleki volcano, near Lake Rudolf, are noticeably active now and probably are of more recent date. Amongst the Pleistocene and Recent volcanoes must be reckoned also the Kyulu⁴² series of young well-preserved cones and craters surrounded by radial streams of lava composed of olivine basalt. This chain of volcanoes runs parallel to the Uganda railway near Kibwezi, Tsavo, and Sultan Hamed stations. The volcanic rocks in the Mau district⁹ are of the nature of phonolites and phonolite-trachytes with others closely approximating the kenytes, and probably belong to the Laikipian period of eruption.

Maufe distinguishes only two clear phases of vulcanicity: (i) an earlier or plateau type, and (ii) a later or cone type, and these are respectively characterised by great horizontal flows of lava and by volcanic cones and craters.

The lava-flows of the plateau-type occur in nearly horizontal sheets, 20 to 40 ft. thick (though occasionally as much as 100 ft.), and have their upper and lower surfaces exhibiting the usual vesicular structures, the vesicles being filled with zeolites, opal, chalcedony, etc. They seem to have been erupted successively without long periods of cessation. Many different petrological types have been recognised^{40 57}, but phonolites¹⁷ are stated to be the most widely distributed, and perhaps the most abundant. Basalts, nephelinites, trachytes, and rhyolites are also common.

According to Holmes¹⁵, throughout the eastern half of Africa from the Cape to Abyssinia, and still farther north and east to southern Arabia and the Deccan in India, the alkali series of lavas, including the phonolites, is later than the amygdaloidal basalts, andesites, and rhyolites¹⁵. The relations of the lavas of the two Rift Valleys to their tectonic setting have been discussed by Bowen⁶⁸ and Groves⁶², and the Reports of the Uganda Geological Survey refer to them, for it has been suggested⁶² that the potash-bearing lavas are associated with the Western Rift Valley of supposed 'compressional' tectonics, whereas the Eastern Rift Valley with its sodic lavas is of 'tensional' origin. Kent¹³⁵ has suggested that rift faulting has repeatedly ended volcanic extrusive periods, and suggests that under the compressional theory of rift-faulting (see p. 64) this coincidence is explained by the closing up of the fissures and outlets¹ for the lava, thus denying Gregory's view that the volcanic action was a direct cause of rift-faulting. According to Kent the chief volcanic period was the Miocene, and the sequence of lavas in the three areas of Lake Rudolf⁴⁵, Nairobi district, and Kavirondo¹⁸⁴ during the Miocene and Pleistocene agrees. No evidence of Cretaceous or Eocene volcanic eruption is present there, and only doubtfully of Oligocene. There is a mass of nephelinite plateau-lava at the north-east corner of Lake Victoria^{11 21 84 140} below the Kavirondo Gulf and on Rusinga Island, which belongs to the late period of vulcanicity, and is probably of Pleistocene age. It agrees with the similar rock on Mt. Elgon. In the Homa Bay area, Kavirondo, and in the Ruri Hills, the 'limestones' are regarded by Pulfrey¹⁶³ as carbonatite masses showing considerable variation in contents invading the earlier volcanic rocks, and followed by intrusion of syenites and finally by more alkaline lavas. A general description of the young volcanic rocks along the Uganda Railway has been given by Goldschlag¹⁴⁰.

KENYA COLONY AND UGA

To the oldest eruptions belong some of the lavas 01 mount; k e n y a , which is a much-eroded volcanic cone, 17,000 ft. high, the highest peak of which is formed by a central plug of an olivine-bearing nepheline-syenite, while the walls of the crater are represented by tuffs, agglomerates, and ashes. The order of the series of lavas is here different. The earliest lavas which were poured out from it were phonolites ; the next and main lava series consisted of kenytes ; and finally there was an eruption of olivine-basalts mostly in the form of dykes on Mount Kenya itself, but also occurring as flows near Mount Hohnel. Some, however, of the olivine-basalts on the lower slopes may be earlier than the kenytes. Mount Elgon^{50 76 127 130 161} is a caldera surrounded by a rim of high peaks. The first eruptions were of lavas of the nephelinite character with some pyroclastics. A series of melilite- or nepheline-bearing basalts followed ; pyroclastic rocks are, however, predominant. The caldera itself is formed of later eruptions of phonolitic nephelinites, and during this stage dykes of a bergalite type were injected. The Gwasi nephelinites resting on Lower Miocene beds^{160 160a} on the eastern shore of Lake Victoria are probably approximately contemporaneous and are placed in the Upper Pliocene. But Bailey Willis^{75 80} believes that Mt. Elgon is the oldest of the East-African volcanoes. Davies¹⁶¹ considers that the beginning of the activity of Mount Elgon took place in the Lower Pliocene, but the main activity in the Upper Pliocene. North^{126 127 129} of Mt. Elgon Tertiary lavas compose Mts. Debasian and Moroto, while from the low cone of Mt. Marsabit flowed out the great lava sheets which spread over the plain, extending to the southern end of the east shore of Lake Rudolf^{41 75}.

According to Mauritz³³ all the eruptive rocks of the Rift Valley belong to the foyaite-thermal series, but Neilsen^{42a} has recognised many different petrological types.

Mount Jombo^{16 3156 97}, south-west of Mombasa, may be regarded as the remnant, or eroded core of a volcanic cone like Kenya. It is composed of a mass of nepheline-syenite associated with the rare rock ijolite and with camptonitic dykes which traverse the surrounding Duruma Sandstones; it probably belongs to a late period of vulcanicity. In the northern part of the Northern province of Kenya⁷⁰ and east of Lake Rudolf^{84 129 131} the Chalbi desert ends at the escarpment which is formed by plateau lava-flows. They were succeeded by a volcanic phase of the Hawaiian type responsible for the flat cones of Marsabit^{86 129 145}, Huri, and perhaps Esie⁸⁶. Farther south to the east of Isiolo is the chain of puys forming the Jombeni range and rising from a lava plain extending eastwards.

In the Turkana⁶⁴ the succession of lavas according to Arambourg¹⁵⁰ corresponds with the Laikipian Series of Gregory in the Rift Valley. The oldest are basalts forming great flows and sheets. These are followed by hyper-alkaline phonolites, and these by rhyolites. In this region⁶⁴ volcanic rocks cover large areas west of Lake Rudolf, but the rocks of the Basement Complex crop out at various places beneath them. The volcanic rocks range from rhyolites to nephelinites and phonolites with a preponderance of rhyolitic and basaltic types. Some tuffs also occur. The latest lavas are the trachy-basalts from the Teleki volcano at the south end of Lake Rudolf^{101 103}. This volcanic region at the south end of Lake Rudolf has been described by Fuchs^{45 79 84}, Champion^{101 103}, and others¹³³. The central island⁷⁹ in the lake is entirely of volcanic origin and is chiefly composed of several explosion craters, two of which hold lakes. Fumaroles still exist on the island. Mt. Teleki^{101 103 133}, south of the lake, is still a dormant volcano.

In the Western Rift Valley on the south-east side of Mount Ruwenzori and south of it to Lake Kivu there are numerous crater lakes as well as Lakes Edward and George, the latter of which does not lie in the Rift Valley. The

petrology of the volcanic rocks and the crater lakes has been described by Holmes and Harwood^{95 102}.

In Uganda, apart from the Western Rift Valley, there was volcanic activity towards the close of the period during which the Kaise beds were deposited, and it took place in a series of belts extending north and south of Fort Portal⁹⁶. The rocks from these eruptions include tuffs, apparently of melilite basalt, and contain fragments of pyroxenite and allied rocks. Post-Kaise movements followed and were succeeded by a second phase of vulcanism in which explosion-craters were blown out. The rocks of this stage include tuffs and agglomerates with ejected blocks of potash-nephelinite and leucitite, and volcanic bombs of leucitite and olivine-leucitite. The petrological characters of these rocks have been minutely described by Holmes and Harwood⁹⁶ and Simmons⁵⁸. The crater at Katwe^{93 110 172} consists of three contiguous circular depressions, two of which contain the water composing the lake of that name. It is an explosion crater, and two other lakes in the vicinity also lie in volcanic craters. The ejected blocks of the Katwe crater¹¹⁰ are mostly amphibolites and metamorphic rocks which are probably Pre-Cambrian in age, but the lava-bombs consist of olivine-nephelinites and olivine-leucitites. Amongst the ejected blocks are not only amphibolites¹¹⁰ but pyroxenites and other rocks which suggest kimberlite pipes as in Tanganyika (*q.v.*). The Katwe crater has many points of resemblance to the Pretoria Salt Pan in the Transvaal. The Katunga volcano^{100 161} in south-western Uganda is remarkable for its isolated position and the peculiar character of its lava, a potash-rich olivine-melilite-basalt which has been named * katungite.

In north-western Ankole and in Toro, near Fort Portal, explosion craters are the characteristic volcanic phenomena, and lava-flows are mostly absent¹⁶¹, but tuffs and agglomerates are present. In the south-west corner of Uganda lie some of the great group of the Bufumbira (Birunga) volcanoes^{39 53 102 143 146}, most of which are situated across the frontier in Belgian territory¹²⁵. The vulcanicity probably began in pre-Pliocene times. In Uganda there are only three principal volcanoes and thirty-four minor vents of this group, not all of the same age. The oldest is Sabinyo, which poured out lavas mostly of a basic andesite type⁵³; the lavas of the other two vents were leucite-basanites. The flows from the smaller vents were also leucite-bearing lavas⁵⁸. One of the later lava-flows from the western end of this group of volcanoes blocked¹⁴⁷ the northern end of Lake Kivu and diverted its outflow to the south into Lake Tanganyika.

The volcanoes of the Great Rift Valley, especially the smaller cones, are largely composed of greenish-grey volcanic ash. The intercalated sedimentary beds consist of sand, fine gravel, mudstones, and shales, but they are not common; in places they have thin layers of flint interbedded.

Recent and Superficial Deposits.—In the coastal region and the islands of Zanzibar and Pemba coral reef-limestones and coral sands and sandstones have a wide distribution, and raised reefs are common^{25 31 35}.

In the gneissic region an iron stone formation, known as 'murram,' covers the surface; this is a ferruginous hard mottled yellowish brown or black product of long continued weathering of the ancient crystalline rocks. It is sometimes pisolitic and varies in thickness from a few inches to 5 ft. In the Eastern Province the murram consists chiefly of lateritised pebble-bearing alluvium which bears little or no relation to the solid rocks below⁹⁸. East of Marsabit in the Northern Frontier Province the Merti Plateau, rising 500 ft. above the plains, consists of consolidated sands and pebble-bands of **alluvial origin**, indicating the former presence of lacustrine or fluvial conditions, for the desiccation of this region has been progressive for ages, and is still

continuing. To the west of Lake Rudolf to the Sudan^{45 79 126} frontier the surface is occupied by Recent or late Tertiary æolian or lacustrine deposits.

A black cotton-soil called 'regur' occupies the surface of basaltic rocks and covers open rolling grass plains (*e.g.* the Athi and Kapiti Plains). It is likewise a residual accumulation, and is very widely spread. At its base (or occurring as scattered nodules through it) there is often a calcareous deposit known as 'kunkar.'

A red residual clay occurs only in the forest regions, such as Kikuyu and Mau, and at the foot of the Manga escarpment, or in regions recently covered with forest, and it is found always above the murram.

On the floor of the Great Rift Valley there is in places (*e.g.* Lake Naivasha) a yellow loam, and occasionally white clay. Calcareous nodules (kunkar) occur in it.

The deposits of silica and the silicification of the lacustrine beds in the Great Rift Valley are connected with the hot springs occurring along the fault-lines.

Climatic Changes^{69 89 106 124}.—The existence of a colder climate in Pleistocene and Recent times is evidenced by the occurrence of moraines and other traces of the lower descent of the glaciers on Mount Kenya to a level several thousand feet below that which they now reach^{18 21}. Nilsson^{50 69 89 105 124} has described this glaciation also on Mount Elgon, and Geer⁸⁷ has described Palaeolithic varves. At the foot of Mount Sabinyo in the Bufumbira group of volcanoes in south-west Uganda large areas covered by moraines and fluvio-glacial deposits with erratics 5-10 ft. in diameter have been described¹⁴⁸, and on the slopes of Mount Ruwenzori there is similar evidence of the lower descent of the glaciers. Leakey^{109 137 144} and Kent¹⁰⁶ have given recently the fullest detailed accounts of the Pleistocene changes of climate and succession of deposits in Kenya and Uganda with special reference to the Pluvial and Interpluvial periods. The terraces and deposits in the valleys and around the lakes embrace the whole period of Pleistocene and Recent times, the later ones containing human artefacts and species of the living fauna¹⁴⁴. The theory of pluvial periods in Uganda is more or less discarded by Solomon¹²², who would explain the field evidence by earth movements rather than by changes of climate, and he maintains that the pre-history of Uganda is independent of that of Kenya and Tanganyika. The history of the great lakes in connection with the climatic changes and the formation of the rift-valleys, particularly in Pleistocene times, has been discussed by many geologists, especially by Gregory⁴², Wayland^{44 58 72 77}, Worthington⁹¹, Fuchs^{45 79 84 152}, Leakey^{106 109 137} Nilsson^{69 89 124}, and Solomon¹²². Three Pluvial periods during the northern glacial period and two post-glacial periods have been recognised by Nilsson, Fuchs^{79 84 152} has specially traced the sequence of events around Lake Rudolf by the Raised beaches, which point to the rise and fall of the lake. In Leakey's *Stone-Age Culture in Kenya*¹³⁷ the earliest Pluvial period, which is called the kamasian⁴², is supposed to correspond with the Gunz and Mindel glacial stages, and the *Gamblian*, or second Pluvial period, with the Riss and Wurm glacial stages. The interpluvial dry period is between the Kamasian and *Gamblian*. The Kamasian series has yielded implements of the Chellean type. In the Lake Baringo basin the Kamasian deposits consist of aqueous tuffs thickly interbedded with gravels and clays. In places the gravels are covered by lavas, and the beds are broken up by the east-west faults as well as by erosion. These sedimentary deposits belong to the first Pluvial period. The second Pluvial period includes deposits of volcanic ash and tuffs. These belong to the *Gamblian period*, and contain fragments of pottery and obsidian artefacts in the beaches at levels of 15, 25, and 30 ft. Later fossiliferous marls,

which contain freshwater shells living in other Central African lakes, rest unconformably on tuffs, the lake level having then risen to a height of 100 ft. above its present position. It is held by many geologists that the position and elevation of the ancient beaches and terraces around the lakes in the Great or Eastern Rift Valley are due not only to the rise and fall of the level of the water but also to subsequent earth-movements, as Bailey Willis⁷⁵ has pointed out. There is stated to be a noticeable correspondence between those in the Victoria and Albert basins^{77 143} and those in the Fayum in Egypt. The various cycles of erosion and consequent development of successive peneplains in East and Central Africa have been dealt with by Dixey¹²¹ in detail from the earliest times.

ECONOMIC GEOLOGY 43 93 109 116

Few mineral deposits of much importance, except gold and soda, have been worked as yet, and questions of economic geology chiefly relate to the soils and water supply. The characters and distribution of the three chief superficial deposits of agricultural value, *i.e.* the cotton soil (regur) the red clay, and the yellow loam, have been briefly mentioned above.

Soda.—Of alkaline lakes, Lake Magadi in the Great Rift Valley²⁶ is the best known. From the sides of the scarp the hot soda springs issue, depositing the silica near the source of origin, and the sodium compounds in the lower parts of the valley. The deposit shows nearly 84 parts by weight of soda in almost equal proportions of the carbonate and bicarbonate, and only .07 parts by weight of silica.

Near Kendu on the Victoria Nyanza there is a lake, Simbi, occupying an explosion crater in micaceous sandstone, probably of Pliocene age. The water is highly charged with carbonate of soda, and from the fact that the level of the lake is rising it is believed that the alkaline springs are still flowing into it. Sodium chloride as well as sulphate and carbonate is obtained in large quantities from Lake Katwe^{72 93}, where there is also a proportion of potassium salt in the water. The hot springs at Kibero on Lake Albert are charged with sodium chloride which is obtained by the natives by evaporation.

Gold.—In the Kakamega^{67 115} and adjoining areas, as in Kenya, gold-bearing quartz reefs are being worked. The reefs occur in the Karagwe-Ankolean Series of metamorphic rocks, comprising schists, phyllites, conglomerates, greywackes, etc. There are also mineralised zones, and all have suffered silicification and invasion by igneous rocks, gabbros, granites, porphyries, dolerites, etc. On the north-east corner of Lake Victoria in the Eastern Province in the Budama area alluvial gold is found. Other auriferous localities have also been discovered¹⁶¹. In Uganda some of the gravels are auriferous, but of little value so far as they have been examined⁷². In the

Buhwezhu Mountain area north-west of Mbarara in Uganda¹⁶¹, where the Karagwe-Ankolean rocks are developed, gold is known to occur.

Iron.—The natives smelt the surface ironstone, locally known as 'murrām,' for iron, and this substance also furnishes excellent road-metal. There are some fine iron-ores^{43 72} in Uganda, ranging from limonitic ores to haematite-magnetite schists. The latter are interbedded with the Karagwe-Ankolean phyllites and contain from 73 to 93 per cent, of ferric oxide. These occur near Kabale, near Kigezi, at Kinkizi, near Rutoba, and near Kampala.

Tin.—The tin deposits of Uganda^{43 59 72 83 92 93 116 161} occur in the southern portion of the Protectorate in quartz-bodies and veins, and in tourmalinised zones of schistose phyllites of the Karagwe-Ankolean System or in the tourmalinised quartzites near the edges of the quartz veins as well as in the associated pegmatites. In the Katenga deposits¹¹⁰ the Karagwe-Ankolean argillaceous sandstones and shales are much metamorphosed by intrusive granites and the cassiterite occurs in shatter and shear zones as well as in quartz veins.

Alluvial deposits in the Katenga area also contain cassiterite grains and worn crystals.

Copper.—At Kilembe^{72 93 161}, at about 5000 ft. above sea-level and about 13 miles from Lake George, large deposits of copper ores have been discovered. The country rocks are metamorphics of the ancient crystalline complex, and mostly hornfelses with some schists. Intrusions include a thulite-bearing rock, muscovite biotite granite, amphibolites, and cutting these intrusives a dolerite. Alaskites¹⁶¹ occur as dykes invading the hornfels and amphibole rocks. The copper ores are chiefly sulphides. Linnæite is often associated.

Petroleum.—In Uganda the Kaiso bods in the Lake Albert basin show oil seepage at various points⁹⁵ on the eastern shore and at the south end of the lake near the River Kisegi. The sandstones of the underlying Kisegi Series contain traces of petroleum.

Phosphates.—Some of the calcareous volcanic tuffs of Toro⁷² contain 2-3 per cent, of calcium phosphate, but have not been utilised.

Soapstone.—The Kisii soapstone is being obtained at Kitere in South Kavirondo, and used as a substitute for talc and other purposes.

lime.—The Pliocene travertine on the shore of the Victoria Nyanza is burnt for lime, and is of some value owing to the absence of calcareous rocks in the interior.

The Rift Valleys and Plateaus^{3 6 19 21 26 27 28 29 31 39 44 46 47 75 79}
 120 142 153.

East Africa owes its surface-relief largely to fractures and subsidences, or broad massive upheavals of the crust, but not to folding.

No true fold-mountains occur in this region, the existing elevations being due to simple uplift along lines of fracture, or to the accumulation of volcanic materials or to differential erosion. But the axial line of the African continent running from north to south nearer the eastern than the western border—termed by some writers the Central African Range—forms the crest of an immense, though gentle, undulation of the earth's crust which has been broken longitudinally by meridional faults. The theories as to the causes and nature of the movements are discussed below.

The chief peculiarities consist in the development of horsts or 'block-mountains' and of trough-subsidences of extraordinary length, while in close connection with the systems of fractures there are widely spread volcanic phenomena.

Extending northwards from the southern end of Lake Nyasa (and possibly from the Urema trough in Portuguese East Africa and along the eastern border of Rhodesia and the Lebombo Mountains still farther south), and reaching as far north as the Red Sea and beyond it into Palestine and northern Syria, there is a gigantic longitudinal zone of shattering or system of parallel fractures marked by trench-like depressions. But there are also transverse or oblique systems of faults, and they may all be grouped into three main sets : (1) the principal one is meridional and is associated with important lines of volcanic activity ; (2) the second one is known as the Somali group, because it forms the edge of the Somali Plateau, and it trends from south-west to north-north-east; (3) the third or Erythraean group runs from north-north-west to south-south-east, and is parallel to the margins of the Red Sea. Members of all these three systems intersect near Mount Kilimanjaro²¹.

These fractures^{42 46 75 142} are either linear or curvilinear, and several parallel members of one set usually occur together, and are specially remarkable for their persistence and the trough-like depressions which they have produced between them.

The rift valleys which result from these dislocations are not simple sunken troughs between lines or faults, but are strips of country affected by several more or less parallel fractures as step-faults in linear series with sunken blocks of the crust between them. These blocks have not all dropped to the same extent and are often tilted, nor do the troughs form continuous valleys, for in places elevation has occurred along them. The fault escarpment also on one side may persist after the opposite one has died out, and the throw of the same faults may vary along their course. The transverse

system of faults which crosses the Rift Valleys in places is the cause of the unequal levels of the blocks of the valley-floor, and has led to the formation of the 'grid-structure' described by Gregory⁴². These transverse faults belong to the second rifting period, and cut across the N.-S. fractures breaking up the floor into blocks at different levels, so that the basin of Lake Rudolf lies at a height of 1300 ft. while that of Lake Naivasha lies at a height of 6200 ft.

According to Wayland^{72 95} the great mass of Ruwenzori⁴ is considered to have been thrust up before the sinkage of the Rift Valley, but Michot^{98 117 118 119}, as above-mentioned, interprets its origin otherwise.

The earth-movements have acted intermittently and at various times as well as in varying degrees of intensity along these lines, and there is evidence that a state of quiescence has not yet been reached⁴⁹. Thus in the case of Lake Nyasa (see chapter on Tanganyika) we find recently upraised lake-deposits near Mount Waller, an absence of deltas, and a shortness of the rivers flowing into it on its east side, together with an absence of sediment on the floor of the north end of the lake, all of which features point to the recent date of these disturbances. Earthquakes⁴⁹ in the Rift Valley are also common north of Lake Albert, and changes of level in the course of a few years have been observed in this region¹³⁵. Lava-flows blocked the valley north of Lake Kivu¹⁴⁷ and changed its outflow.

Two characteristic features are noticeable in these rift valleys : (1) the presence of active or recently extinct volcanoes on their floor, and (2) the existence along their course of a series of great lakes¹⁶⁹, for the chief lakes of East Africa lie in them.

Commencing with the southern portion of the meridional rift valleys, we find that at the north end of Lake Nyasa there is a bifurcation of the trough in which the lake lies, one branch going north or north-north-east up the Ruaha Valley and forming ultimately the Great³ or eastern and meridional Rift Valley which enters the south side of Kenya after traversing the intervening Tanganyika Territory. The other branch bends to the north-west, and is directly continued into the valley holding Lake Rukwa. This valley strikes the east side of Lake Tanganyika at an acute angle and perhaps crosses it. At the point of bifurcation at the north end of Lake Nyasa there is a great volcanic centre (see 'Tanganyika Territory'), from which alkaline lavas have flowed out subsequent to the formation of the rift and have overlapped its western margin.

The western system of meridional faults^{42 75}, along which the chain of the largest African lakes lies, is curved and seems to be

connected in the south with the trough-valley in which the Lualaba River and Lake Mwero are situated, and not directly with the Nyasa trough. Along the course of this western trough are Lakes Tanganyika, Kivu, Edward, and Albert. The Birunga (Bufumbira) group of volcanic mountains¹⁰², lying between Lake Tanganyika and Kivu and including several active vents, blocks the flow of water to the north¹⁴⁷. These mountains do not interrupt the structural continuity of the valley, and are of later origin than the depression into which their lavas have flowed; they form now the watershed in the trough between the Nile and the Congo. Farther north lies Lake Edward, at the north end of which the Ruwenzori mass^{4 98} projects into the trough from its eastern face. But the valley still maintains its trench-like character with parallel walls, and, scarcely decreasing in breadth, is prolonged into Lake Albert⁴⁴ with a continuous curvature to the north-east. The greatest depth of this lake is only 157 ft. Its waters issue from its north end to form the White Nile, and from this point the zone of dislocations appears to be continued northwards by the zigzag escarpments on the west side of the Nile from Wadelai to Gondokoro, which are due to two or three sets of faults²⁹. This Western Rift Valley ends near Nimule in the Sudan⁷⁹.

The Eastern or Great Rift Valley described by Gregory^{3 42} contains several lakes (*e.g.* Lake Manyara, Lake Natron) south of the Kenya frontier,* and north of it holds Lake Magadi²⁶, Lake Naivasha, Lake Nakuru, Lake Baringo, and Lake Rudolph, with hot springs and volcanoes along its whole course. According to Fuchs⁸⁴ Lake Rudolf does not lie in a rift valley but in a faulted synclinal in the rift-area; the western¹⁵² margin appears to be partly determined by a long fault for much of its length, and it is here that its maximum depth of 240 ft. is reached, but there is no such fracture along its eastern side. The N.-S. fault on the west side belongs to the Pliocene or later set of faults which affected the country after the outpouring of the Miocene volcanics. The earlier (late Oligocene) movements produced faults running north and south. The latest movements were minor faults at the end of the Middle Pleistocene, when transverse fractures cut across those of earlier date. The fractures some distance to the west of the Lake, which stretch southwards from the Dodinga Mountains in the Sudan in a N.W.-S.E. direction, are pre-Miocene and form the Uganda escarpment.

The western wall of the Rift Valley extends northwards from Lake Rudolf, according to Champion¹⁴⁸, to Mount Zulia at the junction of Kenya, Uganda, and the Sudan. The floor of the Rift Valley

* See Tanganyika Territory.

expands greatly to the west and north-west of Lake Rudolf, and carries several mountain ranges, some composed of the crystalline basement and others of Tertiary lavas (basalts, nephelinites, and rhyolites). Lake Rudolf had previously a much larger size, as shown by the 475-ft. beach-cut terrace on the slopes and cliffs enclosing it, and at that stage its waters escaped through a still existent but dry gorge to the north-west into the Sobat River, and thus into the Nile. Probably this was during the Pluvial period. In the Tanganyika Territory the valley is in some parts not well defined, but is usually traceable by some surface features (see chapter on Tanganyika). In Kenya it is a well-marked feature, and its width is over 100 miles in places; it has the character of a comparatively simple trench. Its floor consists of flat grassy plains, and its sides locally rise in precipitous cliffs forming the Mau escarpment (2500 metres) on the west and the series of step like scarps conjointly known as the Kikuyu escarpment on the east side³¹. The series of faults in this part is very complex^{46 75}, the individual faults probably not running for more than 80 or 100 miles. Two or three main fractures or step-faults with intervening terraces at successive levels have here been recognised, but in places the ground is cut up by many faults into small blocks and, judging from the variation in the direction of the dip, the blocks have subsided unequally and irregularly. At Naivasha there are four distinct fault scarps². The eastern flank of the Rift Valley near Nairobi⁴⁶ shows the scarps to be formed by the meridional faults, which are crossed occasionally by the later cross-faults, resulting in the 'grid structure.' A noticeable feature is a sharp rise in the level of the floor of the trough from Lake Magadi northwards.

Northwards beyond Lake Rudolf^{45 84} the zone of fractures has been traced less distinctly to the coast. Here the western wall of the trench is formed by the edge of the Abyssinian plateau, and a transverse group of faults crosses it, trending to the north-west to form the complex depression of the Red Sea, and another group of faults turns to the east, resulting in the straight lines of the north and south borders of the sunken area of the Gulf of Aden.

Owing to the intersection of these two systems of faults the Red Sea trough itself bifurcates at the south end of the Peninsula of Sinai, one branch continuing up the Gulf of Suez, and the other making an acute angle in the Gulf of Aqaba, to be prolonged up the Dead Sea and Jordan Valley²² III, and thence in a north-westerly direction between Lebanon and Anti-Lebanon to the region of the Taurus folds. This Aqaba-Orontes trough, like the East African *graben* has not a level floor, and the blocks have sunk to various depths along its course (see chapter on Palestine). The Red Sea-Gulf of Suez trough is more complex, and not only step-faults but

broken longitudinal folds have taken part in its formation (see chapters on Anglo-Egyptian Sudan and British Somaliland. It is older too than the East African Rift Valley, and was certainly in existence by the Oligocene, according to Gregory.

The enormous length of these zones of shattering, extending as they do through more than 52 degrees of latitude, *i.e.* from about lat. 15° S. to lat. 37° 30' N., and their general meridional direction (in spite of frequent minor divergences and lateral branches), suggest that they have their origin in the structure of the planet itself, and are not merely of local tectonic importance. According to Gregory^{36 42}, the formation of the Great Rift Valley is due to the rending of the crust between the segment of the earth pressing northwards to form the Alpine fold-mountains of Europe, and that moving southwards in Northern Asia to buckle up the country in front of it into the Himalayan System. The cause and nature of these movements and the origin of these surface features are much disputed, and whether tensional or compressional forces were at work is an open question⁴⁷. Gregory^{36 42} maintained that stretching followed by rupture and depression formed the rifts, and in his book on the 'Structure of Asia' (1929, pp. 33, 34) he held that 'the great meridional belt of ruptures that made the Great Rift Valley of the Jordan, the Red Sea, and East Africa was due to stresses between the northward movements to the west of it and the southward movements to the east of it,' the great mass of Africa acting as the hinterland pressing northward against southern Europe while most of Asia drove southward tearing the original land-mass apart. The tension theory of Gregory, thus briefly described, is rejected by Bailey Willis⁷⁵ and others, and Bailey Willis has substituted the 'compression theory' in which the forces acted in a horizontal plane. The upwarp of the large plateau was accompanied by such horizontal compressional forces as to depress a wedge-shaped mass between upwardly convergent shearing planes, lifting the edges of the valley. The slope of the ground outwards from the elevated edges of the rift valleys as seen in the dip of the rocks is a feature in support of this view. The fracture-lines, or shearing planes, would then be of the nature of high-angle thrust faults, the wedge forming the floor of the valley being forced down between them. But step-faults are recognised to have also taken a considerable part in their formation. There are also the three groups of fracture lines in different directions which have helped to form the main and subsidiary rift valleys. Wayland¹²³ inclines to Bailey Willis' interpretation, but holds that overthrusting as well as upwarping has operated in the Western Rift Valley. Parsons⁴⁷ explanation differs slightly from the above.

It is said that gravity measurements¹⁸⁹ in East Africa support the

compression rather than the tension theory. But it is held by some geologists¹⁵⁸ that normal faulting, accompanied by uplift of the plateau, has been chiefly instrumental in forming the rift valleys. The process has apparently not ceased, as indicated by the occasional occurrence of earthquakes⁴⁹, showing that a condition of stability has not yet been reached. These movements undoubtedly began in remote geological ages, and have lasted intermittently during the whole Tertiary period. Gregory believed that the earliest rifting in the Eastern *graben* took place as far back as Jurassic times, but recently there has been obtained evidence¹³⁵ which seems to show that the first movements were in Miocene times, and the later ones in Pliocene or Pleistocene times. But upwarping certainly took place at various stages and even in post-Pleistocene times. As above-mentioned the transverse faults are, for the most part, later than the meridional; for the scarps formed by the Miocene meridional series are much denuded, whereas those of later date are abrupt and sharply defined, as seen in the Lake Naivasha area⁷⁹. But Gregory held otherwise. There is also evidence that movements have continued till quite recent times, for in East Africa the latest beds affected by them are the raised terraces of the lakes containing shells of the existing lake species. According to Meyer²¹, the principal earth-movements began in Eocene times with the formation of meridional faults; subsequently those of the so-called 'Somali System' running N.E.-S.W. or N.N.E.-S.S.W. were developed, and finally the 'Erythrean System' trending N.W.-S.E. or N.N.W.-S.S.E. was formed. But some of the faults with this latter trend (*e.g.* in the Red Sea) are certainly older than any of the meridional ones. As yet there is no complete agreement amongst geologists as to the relative ages of these different lines of fault and, according to Baily, the meridional faults in British Central Africa in the Nyasa region were later than those of the Somali System, but remarks on this southern area are made in a later chapter. Throughout the whole of East Africa Gregory considered that the oblique or transverse faults were the oldest, and in Palestine Blanckenhorn also maintains that the meridional faults are the youngest of all (see 'Palestine'). Probably several movements took place along the same lines of fault at different periods. The fact that the Miocene deposits of the Red Sea and Suez are cut through by the fractures, and that the same is the case in the Gulf of Aqaba, shows the post-Miocene age of some of them. There is at any rate some evidence that the movements along these fault-lines were related^{68 135} to the periods of volcanic activity.

Lake Victoria Nyanza¹²³, as above-mentioned, had a different origin from the other East African lakes, though the Kavirondo Gulf lies in a transverse east and west trough^{31 58 63 134}. The greater

part of the lake is generally considered to be due to a shallow cauldron-subsidence, but its western shore is a line of fracture, and numerous faults have been observed in the neighbourhood of its shores and to the south of it³¹, and small and great volcanic cones occur on its shores and islands. Oswald⁷ believes that it formerly had a much wider extent, for terraces⁷⁷ and lacustrine deposits of recent date occur in many places around it. Minor meridional faults exist in the area between this lake and the western rift valley.

(Further details of the rift valleys are given below in the description of the Tanganyika Territory and Nyasaland.)

Erosion cycles and peneplains.

Before the deposition of the Permo-Carboniferous (Karoo) beds in East Africa there was a long period of erosion of the uplifted land-mass of Archaean and Pre-Cambrian rocks, resulting in the formation of a peneplain. This is the oldest surviving peneplain. The erosion of the plateaus probably continued during the period when the Triassic, Jurassic, and Cretaceous beds of the coastal district were being deposited under marine conditions. In post-Cretaceous times, but before the Miocene, the coastal plain and interior plateau were uplifted and suffered erosion which lasted till Miocene times, resulting in the formation of a second peneplain¹⁶¹. In Uganda^{58 95 97} the surface is thought to have suffered warping in late Oligocene times, and great basin lakes, such as Lake Victoria¹²³, were then formed. Subsequent movements led to the development of the Albertine Rift. Wayland considers that towards the end of the second Pluvial period further warping turned the Victoria-Kioga drainage into the Nile by way of the Murchison Falls. Dixey¹²¹ has recognised several erosion cycles in central and southern Africa resulting in the formation of more than two peneplains, the one at the end of the Tertiary indicating an uplift of 6000 to 7000 ft.

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SECTION III.—THE TANGANYIKA TERRITORY
AND ZANZIBAR PROTECTORATE

(A) THE TANGANYIKA TERRITORY

General Characters^{1 2 6 8 9 35 82 115}.—The greater part of Tanganyika Territory is composed of plateaus of crystalline and metamorphic rocks—gneisses, schists, and granites, some of igneous, some of sedimentary origin without any organic remains^{27 28 36}. These rocks are a southern extension of those in Kenya and Uganda, and they form the basement of part of the great East African plateau, which here is broken up into several more or less distinct highlands^{90 104}. In the southern part of the Territory there is the Iringa highland^{59 90}, formed by a warped and faulted arch trending from north-east to south-west. It has been repeatedly elevated and eroded, the earliest cycle of erosion being Mesozoic. In Central Tanganyika the high plains constitute the largest plateau forming on the whole a peneplain⁹⁰. The plateau has suffered progressive uplift and erosion during post-Cretaceous, pre-Miocene and Miocene, times. Warping movements have raised it highest along its middle^{90 102 104}. But along the coastal region and extending inland for varying distances there are bedded unaltered and almost horizontal fossiliferous sediments ranging in age from the Permo-Carboniferous to Recent, and of greater variety in age and character than those in the British area to the north.

The Permo-Carboniferous beds (which correspond to part of the Karroo System of South Africa) occur also farther south on both sides of Lake Nyasa, in the Ruhuhu Valley^{41 45 50 50a} on the east side and between the Kivira and Songwe at the north-west end and to the north-east of the Kinga Mountains.

The younger sedimentary beds are limited entirely to the coastal region, forming a broken zone of variable width; they comprise Jurassic, Cretaceous, and Tertiary marine deposits which lie mostly undisturbed or with small dips. This coastal region is bounded on the west by the highlands of Ungoni, Uhehe, Ussagara, Nguru, and Masai, and generally shows a sharp line of demarcation from the main inland crystalline plateau of which they form a part. The great escarpment^{28 29 109} which runs diagonally right across East Africa to the coast of South-West Africa is a line of fault, often traceable without a break for many miles across country and forming in Tanganyika the inner boundary of the coastal zone. The Kalambo Falls⁹⁸ on the river of that name running into Lake Tanganyika

near the southern border of the Territory are situated at the edge of the westerly-facing escarpment of quartzites and sandstones, clay slates and schists (referred to the Kundelungu System). The plateau is traversed by the continuation of the Great Rift Valley, extending southwards from British East Africa, and it is crossed also by several oblique systems of fracture (see p. 63). Certain tectonic troughs lie off the mainland parallel to the coastline and have caused the separation of the islands of Zanzibar and Pemba.

Young volcanic rocks have a great development at the north end of Lake Nyasa³² at the point where the trough-valley in which it lies bifurcates, and they also occur in important masses north of Lake Kiyu in the Central Rift Valley, and again around Kilimanjaro¹⁰. The great mountain of Kilimanjaro (19,700 ft.) on the northern border of the Territory, and the giant craters of Ngorongoro and its neighbours⁴⁴ 75 90 120 on the central highlands are the most conspicuous and important volcanoes in the Territory. But there is a much smaller development of Tertiary volcanic activity than in Kenya and Uganda.

Behind the coastal zone of sedimentary rocks there is usually a wide so-called 'steppe' region where the crystalline basement frequently emerges through the covering of Mesozoic and later deposits, forming isolated mountains (inselbergs) and producing a characteristic and peculiar topography^{2 19 23 28}. In the southern part of the province this type of landscape is specially developed, but it continues uninterruptedly to the Wami River in the north and extends inland in great bays into the highlands. Some of the inselbergs are of large size and seem to be horsts, as in the case of the Uluguru Mountains. There is considerable difference of opinion as to their origin, but in most cases they seem to be due to differential weathering and to selective erosion, the harder portions of the gneiss (particularly where penetrated by numerous quartz or pegmatite veins) being left standing above the general surface of the country. It is recognised that several cycles of erosion have occurred, one in pre-Cretaceous times and another subsequent to the Miocene period of upheaval and fracture, while a third cycle commenced after the early Quaternary uplift and has continued till the present day. These have been described by Dixey¹⁰². A provisional geological map of the Territory has been drawn by Teale⁵².

DETAILS OF THE FORMATIONS ^{1 2 22}

The descriptions here given of the geological formations and their order of succession, which is variously interpreted^{101 104 108}, are based on the Reports of the Geological Survey, especially on the work of E. O. Teale⁵² and Wade's classification¹¹⁶ of the strata, Behrend³³ and Barnard⁹⁸, and, more recently,

Stockley¹⁰⁴, have proposed other classifications and correlations of the rocks (see below).

(1) **Basement Complex**^{17 30 36 37 39 47 51 52 55 56 57 58 59 86 104}.—This complex and composite formation or group of formations, consisting of metamorphic, igneous, and sedimentary rocks of diverse characters, covers by far the largest area of exposed rocks west of the narrow coastal belt of Mesozoic and later deposits. The complex has been provisionally divided lithologically into three age-groups which are probably separated by great unconformities. The lowest group is typically a highly-crystalline formation consisting of composite or banded gneisses, granulites, crystalline limestone, and schists of various types and origins. The middle group is essentially an igneous series, and consists chiefly of granite-gneiss, strongly foliated, but its precise relation to the upper and lower groups is uncertain. It is well developed in the Lupa region. The uppermost group consists of a metamorphosed complex of intrusive and extrusive igneous and sedimentary rocks of many types, including various schists, quartzites, banded-ironstones, and acid intrusives, and in many respects resembles the upper portion of the Swaziland System of South Africa.

Stockley¹⁰⁴ has recently suggested a new classification and nomenclature for the pre-Karoo rocks of Tanganyika which would probably apply also to Kenya and Uganda. The term '*Basement System*' he would restrict to the lower division of the above-named Basement Complex; it comprises crystalline limestones, meta-sediments, gneisses, granulites, etc. The Upper division of the Basement Complex, which is found in the 'Musoma and Kavirondo regions and includes the banded ironstones, he would term the *Nyanzian System*, and compare it with the Dalradian of Scotland, the Dharwar of India, and the Keewatin of Canada. It chiefly consists of volcanic rocks of many types. In the region⁵⁶ to the south and south-east of the Musoma district Stockley has described in the Upper Basement Complex a group which he terms the *Musoma Series* and which includes banded ironstones and pillow lavas like those in the Basement schists of Southern Rhodesia. This area embraces the Serengeti Game Reserve and Plains which are covered with superficial deposits of clays, calcareous grits, and limestones formed by the decomposition of carbonated schists (Tombstone Formation) in the Basement Complex. Stockley would separate off certain conglomerates, felspathic grits, siltstones, and slates typically developed in the north-east Kavirondo area as the *Kavirondian System*, though previously included in the Muva-Ankolean. According to him unconformities exist between these groups or systems, and the Kavirondian is separable from the succeeding *Muva-Ankolean* (=Karagwe-Ankolean ?) by one such break. The Muva-Ankolean consists of a series of quartzites, grits, conglomerates, jaspilites, phyllites, and shales, with acid and volcanic rocks locally⁸⁸ (rarely basic) and highly folded; it is separated by vast unconformities from the systems above and below. The rocks of the Muva-Ankolean system have a huge extent in east and central Africa, and comprise various groups bearing various names and correspond to a great extent with the *Karagwe formation* in Kenya. In South Africa the Witwatersrand and Ventersdorp Systems are thought to represent them. A tillite has been recorded in them as in Kenya, and there are tillites in the Kundelungu System in the Belgian Congo which is more or less an equivalent formation. The Kundelungu System of North Rhodesia and the Belgian Congo is more or less equivalent to the Muva-Ankolean of Tanganyika, but the correlation of these Pre-Cambrian formations in the different areas is a somewhat disputed matter^{86 93}. Between the Muva-Ankolean System and the next or Bukoban there is a great unconformity and peneplanation.

The Bukoban System is found along the west shore of Lake Victoria from the south-east corner of Uganda, via Bukoba in Tanganyika to some 55 miles S.S.W. of Biharomulo. The beds consist of white to reddish, fine to medium grained compact unfossiliferous sandstones of a thickness of several thousand feet, and are flat-lying or very slightly folded; they contain detrital cassiterite derived from granite intrusive into the older Muva-Ankolean sediments, and are intruded by many sills and dykes of dolerite. The Kasanga beds at the south end of Lake Tanganyika are similar in character and are continued westward into the Belgian Congo. The provisional correlation of the Bukoban System is with the Waterberg System of the Transvaal. In the south and south-east of the Musoma district Stockley⁵⁶ refers to this system a series of green conglomerates, purple quartzites, micaceous grits, and shales. In an interval between it and the Muva-Ankolean System he would place the invasion of the younger granites.

The *Uha System* of Teale, which Stockley now ascribes to the Bukoban System (though it was previously thought to be of Karroo age), consists of sandstones and shales of a thickness of about 1500 ft. and covers a vast area for about 90 miles east of Lake Tanganyika and forms part of what was formerly called the 'Tanganyika System.' The so-called 'Tanganyika Sandstones' are identical with the Kasanga-Abercorn Sandstones, and were included by earlier geologists in the now discarded 'Tanganyika Formation'⁵⁵, as rocks of various ages were embraced.

Volcanics of Uncertain Age.—There are several groups of volcanic rocks in the Territory the age, correlation, and relative position of which are uncertain; some probably fall within the period of the uppermost division of the Basement Complex, while others belong to a stage between it and the Muva-Ankolean. There are others which may be of still later date, though all are pre-Bukoban; of such are the Malivelo volcanic series in the Lupa goldfield, the Ilunga volcanic series (chiefly felsitic) in the Hunga Range, the Ndembara volcanic series of rhyolitic and andesitic lavas associated with metamorphosed sediments, the Kuria volcanics⁸⁸ of dacites, and quartz porphyry in the Musoma district, and the Kipili volcanics of dacite porphyry on the east side of Lake Tanganyika. There is also a group of ultrabasic rocks near Kidete⁷² intrusive into the Basic Complex. There is, as might be expected, a close correspondence in the development of the formations in the adjoining Belgian Congo, but the terminology used by Belgian geologists^{101 108 126} in this region differs from that used by the Geological Survey of Tanganyika, and their classification of the beds is not the same. The Karagwe-Ankole System, however, corresponds with their Urundi System, and the Bukoban partly with their L unpungu System. The geology of Ruanda-Urundi and adjoining parts of Tanganyika and Uganda has been described by Salee¹⁰⁸, and the maps with his paper illustrate the structure and distribution of the rocks and enable a correlation of the beds in these areas to be tentatively made.

Karroo System.*—Before the deposition of the Karroo beds^{45 50 66} there was extensive denudation and widespread warping of the surface, resulting in the formation of several basins of sedimentation. Two principal groups of occurrences of Karroo beds can be recognised—one in the west comprising the Ruhuhu^{46 66 91 97}, Songwe-Kivira, Namivele and Rukwa, Songwe-Rukwa, and Upper Rovuma areas. These contain all the workable coal-seams. Stockley and others^{45 50 66 91 97} have described the development and palaeontology of these Karroo beds in the Ruhuhu region where they are represented

* For a full description of the Karroo System see 'Union of South Africa.'

by 6000 ft. of sandstones, marls shales, and coals with a basal conglomerate, and they range in age from the Eccla beds to the Stormberg beds of South Africa, thus embracing a period from the Permian to the Jurassic. The coal-seams belong to the Eccla and contain plant-remains^{34 60} (*Glossopteris*, *Gangamopteris*, etc.) together with lamellibranchs⁴¹ (*Palaeomutela*) and reptiles^{46 97} (*Dicynodon*, etc.), as in S. Africa, on several horizons.

The eastern group of occurrences of Karroo beds includes several more or less small areas such as the Tanga Series, but probably most of them were deposited in one basin, except the Kidodi Series, which has an estimated thickness of over 7000 ft. In this Kidodi district⁵⁰, south-west of the Uluguru Mountains, there is a series of sandstones and conglomerates followed by a middle series of calcareous sandstones and carbonaceous shales containing *Glossopteris*, *Palaeomutela*, etc. The uppermost series consists of massive sandstones and carbonaceous shales, including a marine deposit containing shells of *Liebea*, *Pteria*, *Myalina*, etc.^{50a}, of Upper Permian age. This is the first recorded marine incursion in the freshwater Karroo System of Africa. The plants from the Karroo System in Tanganyika have been described by Seward^{34 60}, Gothan⁶², and others, the vertebrate fauna by Haughton^{46 126} and von Huene⁹⁷, and the mollusca by Cox^{41 50a}.

A great mass of amygdaloidal lava, at least 2000 ft. thick, chiefly basaltic in character, and pierced by siliceous veins, is found above the pre-Cambrian Bukoba sandstone, and may be equivalent to the Stormberg volcanics of South Africa (*q.v.*). A limestone, 500 ft. thick, followed by reddish shales and marls, locally silicified and containing indistinct plant-remains, succeeds the lavas. Above them are 2000 ft. of brown or reddish sandstones and shales. All these beds are mostly horizontal and undisturbed, and seem to be of Triassic or Jurassic age. Early Mesozoic plants, probably of Upper Triassic age, from the Tanga Series, have been described by Seward⁶⁰. The Upper Karroo is widely transgressive over the older beds⁹⁹.

Jurassic^{3 61 7 20 24 28 40 54 82 95}.—It is possible, as above stated, that some of the unfossiliferous arenaceous beds in the coastal zone which underlie the marine fossiliferous Jurassic belong to the Lower Oolites rather than to the Trias, but at any rate towards the middle of Jurassic times there was a definite marine transgression across the coastal region which seems to have lasted till the end of this period.²⁴ The oldest fossiliferous marine beds in this area, deposited in a geosynclinal extension of the Tethys sea, are referable to the Bathonian, and the Callovian succeeds them, likewise containing a marine fauna; the facies of the latter, however, is different, for it has a distinct Indian stamp in the case of the cephalopods, the Middle European and Mediterranean elements being subordinate, and many of the species of ammonites occur in the Indian Jurassic Chari and Patcham Groups of Sind. The lamellibranchs, none the less, are predominantly Middle European in character. The beds are undoubtedly only a fuller development of the Jurassic in Kenya above described.

(a) *Bathonian*.—In the Tanga and Pangani district deep borings reveal the presence of limestones containing badly-preserved fossils, possibly referable to the Bathonian, lying beneath beds with definite Callovian fossils. At Kibwendere, behind Saadani, there occurs a calcareous micaceous sandstone full of fossils, including the European species *Pecten lens* and *Trigonia costata*, and a similar rock associated with oolitic or pisolitic limestones behind Bagamoyo contains *Vehpecten abjectus*. At Pendambili on the Dar-es-Salaam-Morogoro Railway are found sandy marls and calcareous sandstones of prob-

* See Chapter on India.

ably the same age⁴⁰, and lithologically similar beds occur in several other localities in the interior yielding fossils which indicate the same stratigraphical age. Farther south in the Matumbi Mountains a grey limestone, partly composed of calcareous algæ with corals and mollusca, has yielded *Vehpecten abjectus*, *Rhynchonella lotharingica*, *Trigonia pullus*, etc. On the Mombasa pipe-line the Bathonian limestones and shales yield ammonites of a decided Mediterranean stamp, and none of Indian character.

(b) *Callovian*.—Typical Callovian is represented at Tanga by a ferruginous oolite containing the ammonites *Macrocephalites macrocephalus*, *Sphceroceras bullatum*, etc., and rests on the Bathonian beds. Behind Dar-es-Salaam⁴⁰ and farther south, the Callovian has a pelagic facies, and at Pendambili above the supposed Bathonian is a hard siliceous limestone with a rich Callovian fauna, including *Modiola plicata*, *Ceromya concentrica*, *Pholadomya carinata*, *Phylloceras disputabile*, and species of *Lytoceras*, *Proplanulites*, *Peltoceras*, *Perisphinctes*, *Belemnites*, etc.⁶⁴.

(c) *Oxfordian and Kimeridgian*.—These beds have here a fuller development than in Kenya. Sandy marls and argillaceous sandstones with ironstone nodules containing Lower Oxfordian ammonites (*Macrocephalites*, *Peltoceras*, etc.) are found at Mtaru behind Pangani, at Saadani, and behind Bagamoyo, but have not so far been discovered elsewhere. The Upper Oxfordian (Sequanian) which occurs at Mombasa with the same general lithological characters extends into Tangaland, where it consists mainly of oolitic limestone. In the Matumbi district shaly clays alternating with more or less calcareous sandstones and limestones contain fossils pointing to the Corallian or Upper Oxfordian, and in the Mahokondo district north-west of Kiswere higher Jurassic fossiliferous beds of a calcareous nature are found containing *Exogyra bruntrutana*, *Ostreapulligera*, *Isocardia striata*, etc., which suggest the Kimeridgian, according to Müller; Dietrich⁸⁰ has described a large number of Kimeridge ammonites from these Mahokondo beds. The Indian affinities of the cephalopod fauna which, as above-mentioned, are well marked in the Lower Oolites, are likewise noticeable in the Upper Jurassic, but there is an admixture of European elements and many peculiar species. On the whole the Jurassic marine fauna of East Africa constitutes a separate zoo-geographical division of the Indian province, and has been termed the Ethiopian sub-province.

The absence of the Tithonian marine type of deposit and fauna was thought to indicate a retreat of the sea from the middle East African region before the Cretaceous period began. But recent work in the Tendaguru district has led Hennig and others¹⁶ to maintain that from the time of the oldest Dogger to the end of the Lower Cretaceous, Tanganyika was never completely raised out of the water, and that a series of deposits were laid down in littoral marine or brackish waters in Tithonian times. In the area about Tendaguru^{16 17 69} these beds reach a thickness of 1000 ft. and are regarded by Dietrich as forming a complete transition between the Jurassic and Cretaceous. There is apparently no break here in the succession of Jurassic and Cretaceous beds⁶⁴. The uppermost beds at Tendaguru^{69 95} are certainly Neocomian, but Kitchin⁶⁵ maintained that all the Tendaguru Series were Cretaceous. Dietrich^{48 80} and Hennig^{68 82} held that they belong to the Upper Jurassic. The question of age is also discussed by Schuchert⁴² and Parkinson⁶⁴. The formation in question, the *Tendaguru Series*, consists of a succession of brackish to fresh-water shales and shallow-water marine sandstones resting on pre-Cambrian granite and gneiss. The oldest members of the sedimentary series are referred to the Upper Jurassic. At the base there is a sandy clay containing dinosaurian remains, and above it come marine '*Nerincea*' sandstones. Two more dinosaur horizons alternate with two more marine sandstones, the

latter of which are characterised by species of *Trigonia*^{42 95}. The 'Upper Trigonia sandstones' and the 'Upper dinosaur clay' are referred to the Neocomian (see below), while the 'Middle Trigonia sandstones' and 'Middle dinosaur clay' are placed in the Kimeridgian. A large number of ammonites, gastropods, lamellibrachs, and other organisms occur in the marine beds^{28 43}, and one of the ammonites from the Nerinsæ zone occurs in the Katrol Formation of India. Of the dinosaurs the Sauropoda are of first importance⁶¹, and some Ornithopoda also occur. The genus *Brachiosaurus* (*Gigantosaurus*) seems to have attained larger dimensions than any previously known land dinosaur, and this genus also occurs in the Morrison Formation of the Great Plains of Colorado, Wyoming, and Utah. The dinosaur zones consist chiefly of greenish shales, though some beds are of a brick-red colour, due apparently to weathering. The reptiles, which include many genera of dinosaurs, have been described by Dietrich⁶⁰, Janensch⁶¹, Reck⁷⁶, and others, and the Dinosaur beds on Lake Nyasa contain the same fauna.

Overlying the Tendaguru Series are about 600 ft. of variegated red and white muddy unfossiliferous sandstones, but beyond Tendaguru they contain many fossils indicating the Urgonian and Aptian, and are known as the *Makonde beds* (see below).

Cretaceous^{3 5 16 17 18}.—The uppermost Tendaguru beds⁴² are referable to the Neocomian, and the affinities of the fauna are with the Uitenhage beds of South Africa. They contain a rich molluscan fauna characterised as stated above by the genus *Trigonia*⁹⁵. Apart from these beds in the Tendaguru district the Cretaceous Formation is known to occur along the whole East African coast from Socotra to the Cape of Good Hope as well as in Madagascar, where it has its richest development, but there are many gaps in the succession. The relations of the Cretaceous to the Jurassic are not everywhere determined, but a complete transition has been recognised to exist in certain parts, as in the above described Tendaguru area.

The Lower Cretaceous, which includes the so-called *Lindi Formation*^{62 82} from its development in that district, is proved only in the southern parts of the region, i.e. in the hinterland of Mtshinga, Kiswere, and Kilwa. It is partly equivalent to the Uitenhage Formation of the Cape Province in South Africa* and to the Utatur of southern India, and some of the same species of mollusca occur in it. Thus about 29 km. north-west of Kiswere grey calcareous sandstones contain the typical Uitenhage species *Trigonia ventricosa* Krauss, together with *Seebachia bronni* Krauss and many other bivalves, and at Ntandi 35 km. west of Mtshinga a coarse conglomerate yields *Gervillia dentata* and many other fossils, including some European species. On the north slope of the Likonde Plateau calcareous sandstones and conglomerates contain species of *Trigonia* of the Uitenhage types.

According to Fraas⁴ and Hennig⁶⁴, in the country behind Lindi the whole succession of Cretaceous beds from the Neocomian to the Cenomanian or to even higher horizons is present, consisting of marine limestones, marls, and sandstones, and of those above mentioned the Trigonia beds of Nkundi are regarded as the lowest, the Ntandi beds coming next, and the Likonde Plateau beds then following, but all of them are characterised by species of *Trigonia*. The Niongala beds, which contain species of *Crioceras* and *Ancyloceras* and *Vola*, *quinquecostata*, succeed them, and consist of calcareous sandstones; they are probably of Barremian, but possibly of Cenomanian age.

In the hinterland of Kilwa Kivindje sandstones and arkoses containing *Exogyra columba* and *Vola quinquecostata*, etc., are succeeded by oolitic lime-

* See 'Union of South Africa' for description of this formation.

stones full of a shell-like *Nerinella algarbiensis* Choff. These *Nerinæa* limestones in this district are followed by a limestone containing species of *Menopleura*, *Toucasia*, and *Orbitolina*, and belong to the Upper Urgonian or Aptian, according to Hennig^{6 31}. Probably they are a calcareous facies of the so-called *Makonde beds* which, as stated above, overlie the Tendaguru Series, and are referred to the Lower Cretaceous. A continuation of these beds extends south of the Rufiji River into Portuguese territory. At 41 km. west of Bagamoyo there is a fossiliferous reddish-yellow sandstone (the Kigua Sandstone) at the base of the series which seems to rest discordantly on the Jurassic and yields *Exogyra columba*, *Vola quinquecostata*, and *Orbitolina concava*, and is referable to the Cenomanian. It is believed that these Makonde beds transgress the earlier Cretaceous deposits, and that there was a break in the sedimentation or a period of erosion after Neocomian times. The beds take their name from the Makonde Plateau, where they are typically developed, and form uplands several hundred metres high in the south of the region. In the upper part of the series in the south there is a widely persistent horizon known as the Newala Sandstone, but north of the Rufiji it has been removed by erosion, and is only represented by rolled fragments occurring in later formations. Lithologically the Makonde beds in the Ukwere and Usaramo districts north of the Rufiji consist chiefly of dark clays and marls with limestone bands containing a few fossils, but south of the Rufiji the beds consist of sandstones and clay-shales with some limestones only at the base.

In the Mtunha district, 87 km. south-west of Dar-es-Salaam, a coarse white sandstone contains badly-preserved specimens of *Badiolites*, and has been referred to the Turonian. But it is remarkable that no Senonian beds with a marine fauna having Indian affinities, such as are known in Pondoland, have so far been discovered in the Tanganyika Territory.

Tertiary^{13 87}.—The marine Tertiary beds are limited to the coast^{96 127}, and rarely extend inland more than 25 km., but they reach in some places a height of over 200 metres. They are much more calcareous than the Cretaceous. The Eocene, which occurs between Kilwa and Lindi, is represented by marine marls and clays with layers of limestone, and the beds contain abundant large *Nummulites*, including *N. ramondi*, *N. perforata*, together with *Alveolina* and *Operculina*, the majority of the species in the fauna being known from the Middle Eocene of Madagascar, India, and Southern Europe. Later Tertiary beds rest upon them, and consist likewise of clays with bands of limestone containing fossils at many points; south of the Rufiji they are widely spread along the coast, and occur also on the island of Mafia, where they have yielded many bivalves. In the Lindi district⁶⁴ some of the deposits are of undoubted Miocene age, for they contain the typical Malayan species *Orbitoides* (*Lepidocyclus*) *verbeeki* Newton, and *L. formosa* Schlumb., which are found in the Miocene of Java and Borneo, and the characteristic echinoid genera *Clypeaster*, *Schizaster*, *Echinanthus*, *Echinolampas*, and various lamellibranchs have also been found in them.

Pliocene and Pleistocene.—A boring at Dar-es-Salaam to 530 ft. passed through a succession of marine and estuarine sands, clays, and some coral limestone containing mollusca which are of Pliocene or Pleistocene age, indicating considerable coastal movements¹²⁷. Pliocene deposits with typical species of lamellibranchs have been also recorded from near Pangani.

Mikindani Beds.—Overlying unconformably the fossiliferous late Tertiary beds between Mikindani and Lindi, there are red sandy loams with pebbly layers near the base, which have been termed the *Mikindani beds*, but are of

doubtful age. Beds, lithologically similar, and possessing the same relations, have a wide development not only along the whole coastal zone²⁶ and on the neighbouring islands but also inland, and reach a height of 500 metres in the plateau region of Makonde and Muera, while towards Lake Nyasa they occur up to a still greater height (825 metres). Their thickness amounts to several hundred metres. Bornhardt², who states that they are intimately connected with the underlying marine Tertiary beds, believes that they are of marine origin, *Pecten vassdi* and other fossils being found in them on the coast²⁸, and he suggests that the existing halolimnic fauna of Lake Tanganyika (see p. 86) may be connected with the marine transgression during which they were laid down. But Stapif believes that they are all of terrestrial origin. Possibly they belong to the same period as the Kilindini sands of Mombasa.

The lake beds^{59 71} in the Rungwa Valley at the north-west end of Lake Rukwa consist of sands and clays overlying diatomaceous shales to a thickness of several hundred feet. In one bed fossil fish remains and mollusca 'remarkably like those living now in Lake Tanganyika' have been found. Similar 'sub-fossil' shells have been described^{114 114a} from beds in the vicinity of Lake Kivu and in the Rusizi Valley. In the Njarasa (Eyasi) rift-valley, to the south of the great crater Ngorongoro, there are late Pleistocene deposits containing *Palcearvthropus* and other Recent mammalian remains¹⁰⁷. But the chief Pleistocene beds, most important from their fossil contents, occur in the eastern edge of the Serengeti plains and are known as the *Oldoway beds*⁸³⁻⁸⁶. These consist of about 300 ft. of lacustrine calcareous and sandy stratified clays and contain the remains of a large number of recent or extinct mammalia^{65 96}, and a human skeleton, *Afrikanthropus* Weinert⁹⁶, is stated to have been found in them. They are referred most probably to the Middle Pleistocene, but their precise age is disputed. The *Vogel River Series* of beds to the north of Lake Eyasi⁷³ include the *Lættil beds*, which are composed of sub-aerial tuffs from the Giant craters to the east and contain a somewhat older fauna, indicating a Lower Pleistocene age. Lacustrine deposits also occur near Lake Manyara⁷⁸, and the Tinde bone beds, which form part of the lake deposits of this basin, suggest a correlation with the Kaiso beds of Kenya. In the Lindi and Kilwa hinterland Hennig⁶⁴ has described other Pleistocene or Recent lake deposits. Terrestrial and fresh-water beds containing a special fauna of mollusca, including some extinct species, also occur on the Central Railway¹¹⁵.

Recent formations comprise various superficial deposits, but are chiefly sands which cover large areas, and are principally of sub-aerial origin. Laterite of various types is widely distributed^{28 89}, and surface-ironstones⁷⁷ have formed over large areas. Raised coral reefs along the coast point to recent movements of elevation.

Volcanic Rocks.—The chief period of volcanic activity belongs to the Tertiary and Quaternary, but some eruptions probably date back to late Cretaceous, as in Kenya. The character of the rocks ranging from acidic to ultrabasic is predominantly alkaline, and they include soda-rhyolites and trachytes, phonolites, kenytes, olivine basalts, nephelinites, limburgites, etc.¹⁰⁵. Great outpourings of lava (basalts, andesites, and trachytes) took place at the north end⁸² of Lake Nyasa in post-Tertiary times at the point of bifurcation of the Nyasa trough. There is a considerable variety of volcanic rocks in these mountains; the oldest lavas are trachytes and phonolites, then follow basalts, but the whole succession belongs to a soda province according to Lehmann³². The highest volcano of the group is Rungwe, 10,420 ft., forming an isolated cone³⁷; its lavas consist of trachydolerite and trachyte followed

by atlantite and essexite basalt. Its craters are well preserved⁸⁷. No connection has been proved between the chemistry or composition of the lavas and the tectonic movements¹⁰⁵, though such has been often suspected. Fragmental volcanic rocks also help to form the igneous mass of the Konde Hills¹³⁷ in this region, and some of the eruptions are so recent that the craters have sharp outlines and the rocks are scarcely weathered.

According to Fergusson¹¹, a large volcanic area stretches along both sides of the southern part of Lake Tanganyika south of the central gneiss belt, and north of the sandstone formation surrounding the southern end of the lake. But it is at the northern end of this lake that there is the greatest development of volcanic activity on the western borderland, for here lies the important volcanic region of the Birunga or Bufumbira Mountains on Lake Kivu. These volcanoes, several of which are still active, and rise to a height of 14,000 ft., lie in the Central Rift Valley, and their lavas form a dam between the two lakes¹⁴. They are mostly now in Belgian Territory, but those in Uganda have been described previously (see p. 52). The chief types of lava in this Western Rift Valley are phonolites and phonolitic trachytes¹¹.

The most notable exhibition of volcanic activity to the north-east is represented in the mountains Kilimanjaro and Meru, and in the group of smaller vents around them. This volcanic centre of activity is associated with several faults; Kilimanjaro¹⁰, which rises to a height of over 19,600 ft., appears to lie on an east and west line of fracture, together with Mounts Kibo and Meru, but many other faults running in different directions intersect at this spot. The lavas are chiefly leucitic¹⁰. The crater is 650 ft. deep. According to Jaeger¹⁵, Kibo consists chiefly of lavas belonging to the rock-series of rhomb-porphry, trachyandesite, and trachydolerite, and to a less degree of their tuffs. The rhomb-porphries have the widest superficial extent. The younger eruptions consist largely of phonolite. Fumaroles are still active in the crater.

The Eastern or Great Rift Valley^{8 9} has the active volcano Engai⁴⁴ situated at the south end of Lake Natron, and, farther south, at the junction of the obliquely directed Wembere trough, which enters it from the west, lies the great group of volcanoes which includes the immense crater of Ngorongoro^{90 120} between lats. 3° and 3° 30' S. Still farther south in the same Rift Valley in lat. 4° 28' S. stands the volcano Gurue, 3400 metres high¹.

Glaciation.—The existing glaciers on Kilimanjaro¹⁰ were preceded by others of greater size¹ and wider extent, which descended to lower levels (3700 metres), as is shown by their moraines and other signs of glaciation. We have mentioned similar evidence in the case of Mounts Kenya and Ruwenzori. It is believed that this extension took place in late Tertiary times, and was coincident with a greater rainfall in the country. The latter is also indicated by the old lake-deposits, which prove that the existing lakes are considerably smaller than their immediate predecessors. The whole series of changes in climate¹¹⁸, including the Pluvial periods in Pleistocene times, with the resultant formation of the lake- and river-terraces, have been described by Nilsson^{112 113} and Dixey¹⁰², and belong to the same succession of events as they do in the rest of east Africa as traced by Wayland, Leakey, and others. The changes in the climate during Pleistocene times have had considerable effects on the distribution of life¹²⁸ in east Africa.

Structural Characters^{23 29 52 86 90 109}.—The Tanganyika Territory lies on the same great African plateau as Kenya, and it is likewise traversed by the two rift valleys which have been partially described in the chapter on Kenya. The Great Rift Valley (of which the

northern parts have been described, see p. 62) is well marked as a deeply sunken trough in some places in the Tanganyika Territory, as at the north end near Lake Natron, but frequently it is less obvious, and only the west side of it rises into a distinct surface feature, as east of Iringa, while in some parts no trace of it on the surface has been recognised. The trough is apparently not continuous for its whole length, or the amount of its depression is subject to considerable variation⁹⁰. Volcanoes occur at intervals along it, as above noted, and several lakes lie along it in closed basins formed by the unequal subsidence of the crustal blocks. Such are Lake Manyara⁷⁸ (Laua ya Mueri) and Lake Natron, but most of these lakes are situated to the north in Kenya, and again farther north in Abyssinia. The Western or Central Rift Valley, the northern part of which has been described in connection with the general account of the Rift Valleys, contains Lakes Tanganyika and Kivu, but there are some smaller parallel faults and longitudinal depressions containing other lakes between it and the western shores of the Victoria Nyanza. Of transverse subsided areas the trough of the Wembere steppe, lying between certain faults of the ' Somali System '¹⁰, runs from south-west to north-east into the Great Rift Valley with clearly marked sides. At its eastern end it contains the salt lake of Eyasi⁷³, which is shut in by a group of volcanoes lying within or alongside the trough, and includes the great Ngorongoro crater^{73 90 120}. Bailey Willis⁹⁰ considers Lake Eyasi to belong to the southern section of the great crescent formed by the Eastern or Great Rift Valley, but this valley is not so apparent or continuous in this section as it is farther north, and some authorities believe the lake to lie between another system of faults.

The trough of the Pangani River^{90 114}, which runs south-eastwards to the coast from Kilimanjaro, belongs to the other oblique or so-called ' Erythrean System,' and other faults, probably of the ' Somali System '¹⁰, occur parallel to the coast in the Usambara region.

The trough of Lake Nyasa (see under ' Central Africa ') forks at its north end, as previously described, and the Ruaha trough runs from this point north-eastward towards the Great Rift Valley, or perhaps forms the southern end of the latter, while the Rukwa⁹⁰ branch holding the lake of that name runs in a general north-westerly direction to Lake Tanganyika, agreeing in direction with the Erythrean Group of fractures, and it is stated that the same set of fractures passes over into the Congo territory²⁸.

The tectonic history⁹⁰ of Tanganyika is much the same as that of Kenya and Uganda, but locally differs. The present physiography is intimately bound up with the geological series of events. The earth-movements are of various dates, and the most ancient

structural lines go back to pre-Palæozoic and Archaean times^{28 29 90} — Others are post-Karoo, but are prior to the formation of the Rifts and to the development of the fault systems. The faulting and warping took place on an extensive scale before the existing most conspicuous surface features were developed^{29 52}. It is remarkable that there is no evidence of folding on an intense scale after late pre-Palæozoic times, the features formed by the present Rift Valleys being due to faulting or tilting of fault-blocks by vertical or horizontal movements, as in Kenya. The most detailed investigation of the development and causes of the present topography is that given by Bailey Willis⁹⁰. Apart from the faults connected directly with the formation of these valleys, the whole of East Africa⁹⁰ from the coast to the interior of the Tanganyika Territory has been affected by a series of more or less parallel step-faults¹⁰⁹ cutting the country along N.N.E. to S.S.W. or N.E. to S.W. lines. There is first⁹⁰ the long Ruva-Mombasa fault defining the edge of the continent for most of its length of over 1200 miles, the downthrow of which is towards the Arabian Sea. West of this long fault in Tanganyika there are three step-faults, the Fall line, the Morogoro line, and the Kilosa line, by which we come to the central plateau with an elevation of about 3500 ft. rising in the Serengeti plains by further stages to over 5000 ft. The south-eastern boundary of the Tanganyika plateau is the Fufu fault, which runs S.W. to the south end of the Rukwa⁷¹ trough for 200 miles and meets there nearly at right angles the Rukwa fault trending N.W. for about the same distance. The wall along the north-eastern side of the trough is the actual fault face 200 ft. or more in height and traceable almost continuously for 100 miles. The corner of the Tanganyika plateau between the Rukwa and Ruaha troughs is formed by Mount Mbeya^{47 75}, which is a fault-block with the faults either vertical or hading to the downthrow. It rises 4000-5000 ft. above the general level of the plateau. Between the Rukwa and Tanganyika troughs there is another segment of the plateau forming a horst or vertically-uplifted block.

The Lake Tanganyika trough⁹⁰ is about 450 miles long, 20-40 miles wide, and 2000 to 4700 ft. deep below water-level. It is the deepest lake in east Africa. The least elevation of the plateau above it near the shores is about 1000 ft., so that the total depth of the trough below the peneplain is estimated at 3000 to 5000 ft. The present surface of the lake above sea-level is 2430 ft. It is not walled in by high cliffs or obvious fault scarps, and much of the shore is sinuous and low. Mount Kungwe, which is over 6000 ft. high, is an upthrust mass jutting out from the east coast of the lake. The west coast has some bold and high escarpments in places, but there is likewise great variety in its shores, and Mount Ubwari near its

north end is a long, narrow, steep block nearly detached as an island and has a height of 2300 ft. There are several different types of faulting of various ages which have effected the development of the trough ; the earliest movements subsequent to the pre-Cambrian were post-Jurassic. A general uplift took place with erosion in the Miocene and Pliocene. Vigorous earth-movements of continental extent supervened in late Tertiary and Pleistocene, with local faulting, uplift, tilting, and depression of the trough, some blocks being super-elevated and others greatly subsided. The whole history of the trough is undoubtedly complicated and is at present imperfectly known.

The occurrence of a peculiar lacustrine fauna in Lake Tanganyika¹⁴, possessing a marine facies and hence termed the 'halolimnic fauna,' has been regarded by some authorities as proving the connection of this sheet of water with the sea ; the zoological characters of the shells have been thought to show Jurassic affinities, but by other zoologists these morphological resemblances are considered to be merely superficial and instances of accidental homoeomorphy. Fuchs⁴⁹ has described extinct mollusca in the Pleistocene of Lake Edward in Uganda, which show remarkable resemblances to these living forms in Lake Tanganyika, and he denies their Jurassic affinities. The absence of this halolimnic fauna from all other African lakes, however, proves that the history of Lake Tanganyika must have been peculiar, and, whether or not Moore's theory⁶ of its former connection with the Atlantic by way of the Congo Basin is correct, we must acknowledge that the presence of these peculiar organisms complicates the interpretation of the formation of the rift valleys.

ECONOMIC MINERALS^{36 39 52 122}

Gold^{47 48 56 70 88 94} has been worked in the crystalline rocks in the north-west part of the Territory. The gold, as well as most of the other minerals of economic importance, is associated with the 'younger' granite intrusive into the Muva-Ankolean System, and not with the 'older' granite and Lower Basement Series¹²². The mineral occurs mainly in three distinct regions : (1) the area near Lake Victoria in the Mwanza⁷⁰ and Musoma^{56 88 94} districts ; (2) the Iramba plateau and Selenke; and (3) the Lupa goldfield south of Tabora in the Mbeya district^{47 48 59}. (1) In the Mwanza area^{70 122 123} the gold occurs in granite near its contact with banded ironstones which occur as pendants in it, and everywhere in this district is apparently intimately related to igneous intrusions into these ironstones ; occasionally the gold occurs in thin quartz-veins in the ironstones or in schistose epidiorite. The rocks much resemble those in South Rhodesia¹²³. In the Musoma area^{56 88 94 122} the

gold is obtained from quartz veins and impregnated rocks and the mineralisation is directly connected with the granite intrusions. (2) On the Iramba plateau⁵⁵ the quartz reefs occur in altered and sheared lavas, but granitic and dioritic intrusions are associated. (3) In the Lupa goldfield^{47 48 59 122} the auriferous quartz lenses occur along definite fissures or shear zones in relation to the younger granite intrusions in the Upper Basement Complex, but there are several types of igneous rocks and many dykes as well as gneissose granite. Much placer gold has been obtained here also in the past. In the Ussungu district there are steeply inclined conglomerates alternating with sandstones and quartzites which carry gold and present many points of resemblance to the Witwatersrand 'banket' deposits of South Africa.

Diamonds^{38 54 63 110},—Kimberlite containing diamonds of good quality has recently been found in the northern part of the Territory. On the Iramba Plateau the pipes of kimberlite occur in the granite areas which intrude the altered sediments, and the same is the case at Mabuki and Shinyanga⁵⁴, where the granite pierces schists of igneous and sedimentary origin. The age of the pipes is probably late Cretaceous⁵², but the youngest rocks they pierce belong to the Basement Complex or pre-Palaeozoic periods. The diamonds are mostly obtained from superficial detrital deposits.

Iron.—It is stated³⁷ that enormous masses of high-grade magnetite crop out on the top and sides of Ligunga ridge in Upangwa, and smaller outcrops in the Livingstone Mountains. The itabirite schists are the source of the iron smelted by the natives.

Copper.—The association of copper ores with igneous rocks invading the crystallines near Kidete⁷² is of interest as the ores occur in a suite of igneous intrusions ranging from ultrabasic to acid types such as are found in the Bushveld Complex in the Transvaal.

Tin.—Detrital deposits occur at Kyerwa^{36 52 89} derived from much-weathered schistose phyllites of the Muva-Ankole formation, and the mineral has also been found in the Bukoba Sandstone.

Graphite.—This mineral, which is widely spread, occurs in flakes and veinlets in the schists and other Archaean rocks of the Basement Complex in the Newala-Lindi area¹¹¹ and in the Uluguru Mountains.

Mica and Uranium.—Mica of the muscovite variety is widely distributed and is obtained from the pegmatites of Usambara and other parts; uranium-bearing minerals are won from those in the Uluguru Mountains.

Coal.—Four important localities⁵² where workable coal seams have been proved are so far known : (1) the Namwele (and Muse)

coalfields⁵⁹ in Ufipa; (2) the Songwe-Kivira coalfield at the north end of Lake Nyasa; (3) the Songwe-Rukwa coalfield near Mbeya; and (4) the group of small coalfields on the east of Lake Nyasa. The coal compares favourably in quality with South African coals, but has a rather high ash content. The Ruhuhu coalfields⁹¹ have been described in detail by Stockley^{45 91}.

Salt.—The sodium carbonate and other salt deposits of the Lakes Eyasi¹⁰⁰, Manyara⁷⁸, and Natron are likely to prove of considerable value. Potassium salts have been recorded from Lakes Balangda^{53 100} and Rukwa^{53 71}. But the chief production of sodium salt is from the brine springs at Uvinza in the Kigoma district. The source of the salt in these springs is uncertain. Coastal salt-pans produce also much of the mineral.

Lead.—The Mukwamba lead-deposits occur in shear-zones in metamorphic rocks intruded by granite.

Water¹²².—In some of the coastal regions (*e.g.* Tanga) artesian and sub-artesian conditions exist, but in the arid and semi-arid parts of the interior bore-holes in the granites, schists, and gneisses locally obtain water at depths of 150-400 ft.

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(B) ZANZIBAR PROTECTORATE

The island of ZANZIBAR¹, which has an area of 640 sq. miles, is joined to the coast of the mainland by the 50-fathom line, but the neighbouring island of *Pemba*, which is about half the size, is completely separated, together with its islets, and is enclosed within the 100-fathom line; a deep trough divides it from the mainland, running parallel to the general trend of the Great Rift Valley, and probably marking a line of fault. *Pemba* is composed of two series of beds, the older of Lower Miocene age and known as the *Pemba Series*, and the upper of Pleistocene age. The *Pemba Series* consists of 300-350 ft. of sands, clays, and sandy limestones which are fossiliferous, containing many marine molluscan species of the genera *Aturia*, *Ostrea*, *Pecten*, *Chlamys*, etc., echinoids (*Clypeaster*) and foraminifera (*Lepidocyclus*, etc.)². These beds are succeeded by unfossiliferous red loams and sandy clays with thin lines of pebbles. The Pleistocene series consists of limestones containing corals and recent mollusca. Recent alluvium and red loams rest on the surface. It is probable that *Pemba* island is a horst surrounded by faults; the beds have been folded into simple low anticlines and shallow synclines.

In *Zanzibar*¹ the oldest rocks are of Pliocene age and consist at the base of fossiliferous pebbly and marly limestones (known as the *Zanzibar Series*) followed by unfossiliferous red loams, clays, and false-bedded sands, the whole series being over 400 ft. thick. The limestones contain *Ostrea virleti*, *Pecten vasseli*, *Chlamys werthi*, *Maretia ovata*, *Operculina complanata*, etc.². Above them come a series of limestones, the so-called Azanian limestones, about 100 ft. thick, with some sands and clays in the lower part and coral-reef in the upper part. They contain Recent molluscs and echinoids. The newer Azanian beds are banked against the older portion. The Recent deposits comprise raised beach sands, sandstones, and red loams.

The detrital minerals found in the various sediments in the basal beds of *Pemba* and in the *Zanzibar Series* have been derived from the Archaean rocks of the mainland³.

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CHAPTER IV

RHODESIA AND NYASALAND

General Geological Features.—The greater part of the British area north of the Transvaal consists of crystalline, metamorphic, or unfossiliferous rocks. These extend from the Union of South Africa over Southern and Northern Rhodesia and British Central Africa, and comprise a variety of rocks of different types, which probably belong to pre-Karoo formations of several distinct ages, but their classification and sequence, as well as the correlation of the various exposures of lithologically similar rocks, are to a large extent uncertain. Throughout this whole immense region there is no evidence of marine conditions since pre-Cambrian times, for there is a complete absence of all marine fossiliferous Palaeozoic sediments, and all the late Palaeozoic and Mesozoic or subsequent deposits are of fresh-water or terrestrial origin.

Resting on the fundamental complex are patches of Karroo beds possessing the same general characters and succession as those farther south in the Union of South Africa. But particularly noticeable is the enormous mass of lavas in the Zambesi region which were poured out at the close of the Karroo period, and apparently are equivalent to the volcanic beds of Natal and the Bushveld Amygdaloid of the Transvaal (see p. 136).

With the exception of superficial deposits, no post-Karoo beds are known from the British area, though in Portuguese territory, farther to the east, Cretaceous and Tertiary marine deposits are found near the coast.

Geological Structure.—British Central Africa is traversed by a southward continuation of the great meridional faults of the Rift Valleys, which have been described in connection with Kenya, and Lake Nyasa itself lies in the valley which forms the southern part of the main meridional trough, while a member of the same longitudinal series of faults runs down still farther south to the Sabi River. Faults belonging to the same system or other systems also traverse Northern Rhodesia but without forming rift valleys. Structurally the Rhodesian Plateau itself, which consists of ancient crystalline rocks, appears to be of the nature of a huge dome, the sedimentary strata flanking its margins being known to dip away from it on the north, east, and south. The edges of the plateau seem to be **due** to faulting, and mark the weathered lines of the old fractures. On the

eastern side there is an abrupt scarp nearly coinciding with the Portuguese frontier, and running for over 300 miles from north to south. This marks the course of the above-mentioned meridional fracture extending southwards from Lake Nyasa^{73 100}, which runs close to the thirty-third meridian, and is well defined, the country to the east of it dropping down suddenly 3000 ft. The line of the Sabi-Odzi Valley, which runs approximately parallel to the southern portion of the scarp, corresponds to another fracture. The western and north-western side of the Rhodesian Plateau is bounded by part of one of the north-east to south-west lines of dislocation, comprising the Deka and Machinga (Luangwa) faults⁵⁵, which are traceable, practically without interruption, for over 800 miles from the Wankie district northwards towards the north end of Lake Nyasa^{73 100}, and were the scene of pre-Karoo as well as post-Karoo movements. This tectonic line is intersected in its middle portion by an imperfectly known east-and-west line known as the 'Kafue-Middle Zambesi tectonic line.' Another group of tectonic lines trending north-west to south-east is recognised in the Lower Zambesi region¹³. These four groups of tectonic lines, of which the north and south ones are the most important, have determined the geological characters and, to a large extent, also the present topographical features of Rhodesia¹³ (see below).

DETAILS OF THE STRATIGRAPHY

Pre-Karoo Rocks

(A) In SOUTHERN RHODESIA¹⁻⁴ the pre-Karoo rocks are mostly crystalline and metamorphic, but include some of unaltered igneous and sedimentary character^{30 36 45 48-50 53 55 57 59-64 66 68 70 71 74-77 92}. In the detailed descriptions of special areas the Geological Survey of Southern Rhodesia has used various local names for the different developments of these old rocks. The succession varies locally and no general classification or nomenclature for the various series has been adopted. The intrusion of an older Red Granite, as in the Transvaal, and of a newer Grey Granite separates two main groups of beds, which are also divided by unconformities. In Southern Rhodesia the relations between the batholiths of granite and other plutonic masses and the Basement schists have been described by Macgregor⁵³, who considers" that the latter are the crumpled roof of a continental granitic shell composed of intrusions of various kinds and of different ages. The general succession of the Archaean and Pre-Cambrian rocks is as follows. The oldest form the *Greenstone Series*, chiefly composed of largely-altered and schistose basic lavas (including pillow-lavas), tuffs, agglomerates, and many varieties of schists. These are succeeded by banded ironstones, slates, phyllites, and cherts. This formation has been termed the *Banded Ironstone Series*, and is intruded by various igneous rocks. Folded into these earlier beds there is a series of grits, boulder beds and conglomerates often changed into schists and including the auriferous conglomerates; it is termed the *Eldorado Series*. The correlation of the various divisions, and the sequence of the groups of rocks, is largely undetermined or a matter of dispute, and the Transvaal equivalents are mostly uncertain.

The high veld in Southern Rhodesia is almost entirely composed of these old rocks. The coarse-grained gneisses²⁹ are continuous with those of the Swaziland System of the Transvaal. Crystalline schists, banded ironstones, conglomerates and grits respectively form three lithological groups²⁹. All are invaded by various types of intrusive rocks. The crystalline schists are mostly greenstone 'schists, and include epidiorite—hornblendic, chloritic, and talcose varieties—with serpentines and rocks of intermediate and perhaps acid composition. Some of these schists are altered sediments, but others are certainly volcanic rocks and intrusive sills. The great development of hornblendic rocks is specially noticeable.

The banded ironstones largely represent fine mechanical sediments which have been highly silicified, and their banding appears to be due to recrystallisation under pressure, and is not necessarily in correspondence with the original bedding. Mennell⁴ states that the banding is usually vertical, or nearly so, and runs in straight or parallel lines of red and white, brown and white or other colours. Intercalated among an apparently normal sequence of these beds there will be found extraordinarily contorted layers not usually exceeding a foot in thickness. Such may be seen near Bulawayo and Salisbury. The contorted portions in some places pass into crush-breccias. Occasionally slaty beds are found intercalated in the series. The rocks are always to some extent ferruginous; some parts are nearly pure iron-oxide, but others are jaspersy or cherty. Frequently the series is auriferous¹⁰⁴. Zealley²⁷ has shown that the banded ironstones and jaspers around Gatooma are altered felsitic rocks, and probably this explanation applies to some similar rocks in other areas. There is a great lithological resemblance between these Rhodesian banded ironstones and the rocks which occur on more than one horizon in the pre-Karoo formations of the Transvaal and Cape Province. The iron-bearing Huronian beds of the Lake Superior region in America are said to possess almost identical characters.

The Eldorado Series¹⁰⁴ of Southern Rhodesia includes grits, arkoses, greywackes, and boulder beds, as well as conglomerates which comprise the so-called Rhodesian or Eldorado banket³³⁰ or auriferous conglomerates³⁸ (see 'Economic Geology'). These beds rest upon the ironstones and are of immense thickness, though probably much folded. If the sequence near Bulawayo is normal, they cannot be less than 10,000 ft. thick⁴. Probably the average thickness is at least 1000 ft.³. These conglomerates, which are scattered over an area of fully 100,000 sq. miles, are associated with finer sediments, and are frequently sheared and crushed. In spite of these and other secondary changes due to the infiltration of various minerals, their original character is occasionally preserved, and pebbles of quartz, banded ironstone, halleflinta, schists, granite, granophyre, porphyrite, and amygdaloidal lavas can be recognised. The matrix in the altered and sheared conglomerates may pass into the condition of hornblende-schist. In the Lomagundi district volcanic beds representing ancient lava-flows are found interstratified, and include rhyolites and trachytes, enstatite-basalt, etc. Recently it has been contended that some at any rate of the so-called conglomerates themselves are crushed rocks of an igneous origin. Thus the Shamva conglomerate is stated to be a microgranite and the Eldorado conglomerate to be a sheared felsite²⁹. With regard to their age, the view has been widely held that these conglomerates are of the same general age as the Witwatersrand beds in the Transvaal. Studt¹⁴, however, does not consider that the Witwatersrand System is represented in Rhodesia. In the absence of any uniform development of the beds throughout the whole area, the succession in different areas must be described separately, first in Southern **Rhodesia**.

(1) In the Que⁷⁴ and Gwelo" districts the oldest rocks are termed the

Magnesian Series, and comprise serpentines, talc-schists, magnesite rock, marbles, quartzites, and banded ironstones; they make an intrusive contact with a mass of gneissic granite known as the Rhodesdale granite. Resting unconformably on both there is first a Lower Volcanic Series of pillow-lavas with interbedded jaspilite, etc., followed by an upper group of felsites, etc. An Upper Volcanic Series resting unconformably on the Lower consists also of pillow-lavas with interbedded grits, banded ironstones, etc. It is possible that these Volcanic series correspond either wholly or in part with the Ventersdorp System of the Union of South Africa. After these there begins with another unconformity the *Sedimentary Series* in two groups of greywackes, slates, banded ironstones, arkoses, and conglomerates. This series may correspond with the Transvaal System. Intrusive dykes of dolerite and other igneous rocks of various ages penetrate them.

(2) In the Gatooma district⁶⁰ the most ancient rocks are volcanic lavas, tuffs, and agglomerates of basic or ultrabasic composition. This series is known as the '*Greenstone Series*,' and is often schistose. Into it dome-like masses of granite and other rocks have been intruded at two or more periods, the earliest and principal one being the Rhodesdale gneissic granite. Some interbedded sediments occur in the Greenstone Series. An infolded belt of sedimentary rocks, consisting of three groups—conglomerates, quartzites, arkoses, and some lavas—follows, and into them there has been intruded the '*younger granites*,' etc. Later still are the dolerite and other dykes.

(3) In the central part of the Mazoe Valley Gold Belt^{50 61 75} there is a series of quartzites, quartz-schists, conglomerates, and arkoses below the banded ironstone group which is itself below the greenstone volcanic group. Above the latter comes para-gneiss, and then the *Shamva Grit Series*. Into them are intruded serpentine, felsite, gabbro, granite, and other igneous rocks.

(4) The succession in the Antelope Gold Belt⁷⁶ has likewise a sedimentary group of rocks at the base below the Greenstone Series and banded ironstone groups, and serpentine and granite intrusions follow.

(5) The Lower Gwanda Gold Belt⁷⁷ has apparently no basal sedimentary group, and the Greenstone group here consists of hornblende-schists, amphibolite, actinolite schists, talc-schists, serpentine, etc., and is succeeded by banded ironstones and intrusive granites.

(6) In the Umtali Gold Belt⁶⁴ the Mbeza Sedimentary Series rests unconformably on the Greenstone schists, and is followed by a variety of intrusive rocks.

(7) In the Insiza district around Filabusi⁶² the Greenstone Series has a sericitic quartz-schist group below it, and is followed by the so-called '*Central Phyllite Group*,' consisting of phyllites with banded ironstones, conglomerates, and limestones on certain horizons. The intrusive igneous rocks include several granites, serpentine, and limburgite, as in the Shabani mineral belt.

(8) The pillow-lavas of the Lonely Mine^{48 63} area in the Greenstone Series on the Bembesi River are specially well developed. The only traces of organisms in these various sedimentary beds are certain algal remains in the limestones⁸⁸ in the Basement Schists Series in the Bembesi Gold Belt.

In a region west of Hartley and south of the Umfuli River there is a series called the *Deweras Series*⁶⁶ of conglomerates, arkoses, and volcanic rocks (chiefly amygdaloidal greenstones) on which rests with a strong unconformity the *Lomagundi System*^{28-30 66} which is generally correlated with the Transvaal System of the Union of South Africa. It includes the Sinoia limestones^{30 35 47}, as well as arenaceous and argillaceous beds. The '*Dolomite Series*' of the Transvaal System may probably be correlated with the Sinoia

Calcareous Series and other parts of the System may be represented by the arenaceous beds^{28 29}.

Intrusive Rocks.—All the crystalline and metamorphic rocks have been penetrated by masses of granite, of which the Red and Grey Granites above mentioned are the chief⁵³, as well as by other intrusions⁵. The margins of the granites are often gneissic, and the interlaminar injection of the granites with the schists renders the interpretation of their relations a matter of some dispute. The granite masses occupy a larger area than all the metamorphic rocks, and are of various petrological types. All the normal granites are characterised by biotite and microcline. The most important mass constitutes the Matoppo Hills²² south of Bulawayo, and in this granite the rare mineral orthite is common, especially in the marginal modifications.

It is now recognised that there are granites¹⁴ of an earlier and others of a later date, some being intruded prior to the deposition of the Transvaal (Lomagundi) System, as is the case in the Transvaal itself. There are also felsites³⁶ and quartz-porphyrries and other acid intrusions which have frequently been altered to porphyroid and sericite-schists. But of certainly earlier date than many of the granites² and acid intrusives is a series of ultrabasic rocks, as in the Shabani area⁴⁹, for they are penetrated by the granites, but on their part they invade the metamorphic rocks of the group above described. Such relations between the rocks can be seen in the Shabani area⁴⁹, where the intrusive dunite-serpentine complex is followed by a later intrusion of gneissic granite. It is these ultrabasic intrusions, represented now by serpentines and talc-schists, which contain chromite and asbestos.

The *Umkondo* (=Sabi) System^{4 ON} the Melsetter Plateau, consisting of limestone at the base followed by shales, sandstones, quartzites, and andesitic lavas, are correlated with the Waterberg and Matsap Systems of the Transvaal and Cape. It may be mentioned that Studt¹⁴ claimed that all the so-called 'Forest Sandstones' in Rhodesia should be considered to be of Waterberg age, but the finding of reptilian remains of Upper Karroo age in them near Bulawayo proved that this wide correlation was not correct. The Sijarira Series on the Sijarira Plateau, consisting of quartzites and sandstones, but without fossils, may be also of Karroo age. But it is possible that some of the arenaceous rocks in Bechuanaland described by Passarge²⁶ are of Waterberg age.

(B) IN NORTHERN RHODESIA the *Archæan* (Swaziland System) is chiefly represented by gneiss and schists², and these undoubtedly are merely a continuation of the same complex of crystalline and metamorphic rocks found in Southern Rhodesia. They occur as zones or belts with a general N.E.-S.W. strike, and are intensely folded and penetrated by granites and other intrusions. In north-western Rhodesia they occupy large areas in the Machinga Mountains and the Batoka Plateau, and along the Kafue Valley. Along the escarpments of the Batoka Plateau, and in less disturbed districts, there are quartzites with some conglomerates and phyllites of doubtful age, which in the more disturbed districts generally become schistose, and sometimes show fault-brecciation.

More or less metamorphosed pre-Karoo formations are occasionally folded into these older rocks, and the succession and character of the beds are much the same as in Southern Rhodesia, though different local names have been given. The *Lomagundi* System is well represented, and the *Lusaka* System⁵⁷ or Series corresponds to the *Sinoia* calcareous series in character in north-western Rhodesia, and is succeeded by arenaceous beds known as the *Kafue* System or Series and correlated with the Pretoria Series of the Transvaal.

Studt¹⁴ recognised these representative formations and their correlation with the Transvaal development. Thus, on the west and south sides of Lake Bangweolo⁶ there are white and grey crystalline limestones and quartz schists, and in the Kafue Basin at Broken Hill^{57 112} we find dolomites, etc., forming a series of folds with a strike varying from W.S.W.-E.N.E. to S.W.-N.E., and often highly mineralised, as are similar rocks in the Katanga district^{14 33}. The Broken Hill Series, comprising dolomites, phyllites, and quartz schists, is older than the M'Kushi gneissoid granite and than the Bwana M'Kubwa copper-bearing series which rests on the granite with a great unconformity¹¹². Copper deposits (see 'Economic Geology') occur at various places in the dolomite series, and there are also interbedded iron ores, while lead and zinc ores are found in vertical pipes of dolomitic breccias.

In north-west Rhodesia^{65 67 68 70} the succession of beds and general stratigraphy are best known in the N'Changa⁷⁸ area which lies immediately south of the Belgian Congo border. Here four principal series of beds are recognised above the Archaean ('Basement Schist Series'). First comes the *Muva Series* of quartzites with interbedded chlorite-sericite schists. These beds, which are closely folded with axial trends to the N.N.W. and may be of the same general age as the Witwatersrand System of the Transvaal, are Pierced by the intrusive Muliashi granite-gneiss. Unconformably succeeding these beds and this intrusion is the *Bwana M'Kubwa Series* or *Roan Series*, consisting of a coarse basal conglomerate succeeded by grits, arkoses, shales, dolomites, and cherts, which much resemble in character the Transvaal and Griquatown Series, and is the most important mineralised formation⁴³. Probably it may be correlated with the Lomagundi Series of Southern Rhodesia. This series is intruded by the younger grey and red granites⁷⁰. The *Kundelungu Series*, lying unconformably on the Bwana M'Kubwa Series has three distinct rock-types which occur in different areas: (1) glacial (?) conglomerates with graphitic phyllites, arkoses, and dolomite; (2) biotite schists and granulites; (3) chlorite schists. There are also basic intrusives invading the granites. But the N'Changa red granite is believed to be partly pre-Bwana M'Kubwa in age. A detailed description of the petrological characters of these Pre-Cambrian rocks as developed in the adjacent Mokambo region is given by Lecompte¹⁰⁶. In the Solwezi district⁷¹ lying to the west of the Nchanga area and close to the Congo frontier the Basement Series is closely similar lithologically, but includes gneisses as well as quartzites and schists, and the Muva Series is not separated. Granites, pink and grey, as well as pegmatites, invade the series. The overlying *Katanga System* includes rocks equivalent to the Bwana M'Kubwa and part of the Kundelungu Series. Thick dolomitic limestones occur here in the middle of the system, and a glacial (?) conglomerate occurs in the upper set of quartzites and shales. Basic intrusives (gabbros) invade these rocks. In the district north of the Kafue Valley⁵⁷ there is a peculiar intrusion of acid and basic rocks known as the Hook Granite Complex in the Mwengwa district. The series of limestones and dolomites, called the *Lusaka System* (=Broken Hill Series of Studt), may be correlated with the Dolomite Series of the Transvaal, and an overlying group of quartzites, shales, tuffs, and sandstones, termed the *Kafue Series*, probably corresponds with the Pretoria Series of the Transvaal. Algal remains⁸⁰ have been detected in the Kundelungu Series, as in the Pre-Cambrian rocks of Southern Rhodesia⁸⁸ and the Transvaal.

In north-eastern Rhodesia⁵⁵ the Archaean and Pre-Cambrian rocks have **not** been classified in detail, but are of the Muva-Ankole type and like those in Nyasaland⁴⁰.

In the extreme north of Northern Rhodesia, between Abercorn and Kasama⁷², the Basement Complex is followed by a phyllite and hornfels

series. A porphyrite series succeeds, and then follow intrusive granites and associated igneous rocks including gabbros. On the denuded surface of these rocks rests the *Kundelungu Series* of arkoses, sandstones, quartzites, and shales, pierced by intrusive dolerite dykes. Giant quartz veins cut all these rocks.

(C) In NYASALAND^{23 40} the pre-Karoo rocks, which are closely similar to those in Northern Rhodesia and Tanganyika, may be divided broadly into (a) an ancient crystalline and metamorphic series, and (b) a later sedimentary series, as in Southern Rhodesia. The former series includes : (1) highly metamorphosed sedimentary beds, such as graphitic gneisses, crystalline limestones, quartz- and muscovite-schists ; (2) foliated igneous rocks, especially augen-gneiss derived from granite or syenite ; and (3) plutonic intrusions, usually granite or syenite, and more rarely norite or gabbro. The metamorphosed sediments are exemplified by the quartzitic and micaceous schists of the Nyika, and by the graphitic gneisses, kyanite-gneisses, and crystalline limestones of Central Angonaland and the country beyond the south-west end of Lake Nyasa. The foliated igneous intrusions form much of the Nyika Plateau, and extend west of it, underlying the Karroo beds. The high plateaus of Zomba and Mlanje⁵⁴, west and south of Lake Shirwa, consist of non-foliated plutonic rocks, mostly hornblende-granites and syenites, generally alkaline, with nepheline-bearing dykes. Numerous quartz- and pegmatite-veins traverse the rocks, but probably the intrusions are of more than one date.

The later (6) or 'Sedimentary Series,' tentatively correlated with the Bwana M'Kubwa and Kundelungu Series, is developed in the north-west corner of Nyasaland¹¹⁴ in the Mafingi Mountains⁴⁰, and consists of a great thickness of whitish quartzites, phyllites, schistose flags, feldspathic sandstones, and grits. These beds strike from north-east to south-west, and dip mostly at 40° to 75° to the north-west, but in some places are vertical or overturned. No fossils have so far been found in them. Closely similar beds occur to the north-east across the eastern and northern frontiers.* The precise correlation of these various series in Rhodesia^{65 67 97}, Katanga, the Union of South Africa, Nyasaland, Tanganyika, and Kenya, though on the whole admitted to be all Pre-Cambrian, is a matter at present somewhat unsettled^{33 67 68 96 97}.

In connection with the Congo Basin⁹⁷ the different classification of the rocks and local nomenclature^{43 67 68 70 78 79 97} increase the difficulties, but we may conclude that, at any rate, parts of the Nama, Transvaal, and Waterberg Systems are represented in the formations overlying the Basement crystalline rocks, commonly included in the Archaean. The *Katanga*^{33 97 106} System of the Belgian Congo is undoubtedly the continuation of much or most of the Pre-Cambrian rocks of Northern Rhodesia and Nyasaland, and includes the Bwana M'Kubwa Series and much of the Kundelungu. The classification adopted by the Fifteenth International Geological Congress and quoted by Parker and Gray⁹⁶ in connection with the Rhodesian copper-fields and ore-bearing formations is as follows :—

Katanga System.

Upper Kundelungu Series.

Lower Kundelungu Series.

Mine Series=Bwana M'Kubwa Series.

(great unconformity.)

Muva-Ankole System.

Archæan Complex.

* See * Tanganyika Territory.'

In the Belgian Congo it has been claimed that Devonian fossils have been found in the Upper Kundelungu, but there has been no confirmation of this discovery, nor of the identification of the fossils.

The so-called 'Tanganyika Sandstones' lying to the west of the Machinga schists, and to the north of lat. 12° S., may perhaps be referred to the *Waterberg System*; these sandstones have a very wide development, and reach 3000 ft. in thickness at the south end of Lake Tanganyika.

The Karroo System

This great series of beds which attains an enormous development in the Union of South Africa (*q.v.*), and is there of great economic importance, is of much less extent in Rhodesia, though it has the same general characters. The classification and nomenclature of the beds differ from place to place, and the correlation of the different exposures is at present a matter of some uncertainty.

(A) RHODESIA.—The Karroo beds have been differently grouped^{4 6 7 21} 37 58 89 and bear different names. Where fully developed the succession in Southern Rhodesia is as follows :—

7. Batoka Basalts	}	Stormberg Series.
6. Forest Sandstone		
5. Escarpment Grits	}	Lower Beaufort Series.
4. Madumabisa Shales		
3. Upper Wankie Sandstones		
2. Wankie shales, coals, and fireclays	}	Upper and Middle Ecca Series.
1. Basal Beds and Lower Wankie Sandstones		

These Karroo beds occupy the lowlands of the Zambesi Valley and the floors of the trench-like river-valleys traversing Rhodesia diagonally for 800 miles from the Deka River to the head of the Luangwa^{32 55}.

The correlation with the several divisions of the Karroo System in the Cape Province is a matter of some uncertainty, but the Lower Karroo and the Stormberg Series are undoubtedly represented. In Southern Rhodesia⁹² in the north-western area the Wankie shales and coals of horizon 2, which were called by Molyneux the Lower Matabola Beds²¹, seem restricted to the Wankie area, but the Madumabisa Shales of horizon 4, which were termed²¹ the Upper Matabola beds, are persistent over a wide area north of the Zambesi.

In the **Basal Boulder beds** there is no definite evidence of glacial action as there is in the Union farther south. These basement deposits vary from an angular breccia to a well-worn rounded pudding-stone. In the former there are fragments of gneiss and schist, but the conglomerates are largely made up of pebbles of quartz and quartzite, which vary in size from that of peas to boulders 40 ins. in diameter. These boulder beds have a great development in the area north of the Zambesi in the Lufua and Luano Valleys, and in the latter valley have yielded *Glossopteris indica*. It is doubtful if they represent the Dwyka; the Lower Ecca shales are absent. The *Sijarira beds* above mentioned are now generally put in the Karroo System, and may be of Ecca or Stormberg age.

The overlying **Wankie Coal Series** consists of clays and numerous coal seams, some 6-42 ft. thick, and crop out over wide belts in Southern and Northern Rhodesia. The whole series, which is only 300-400 ft. thick, yields the typical genera *Glossopteris*, *Gangamopteris*, *Schizoneura*, and the lamelli-branch *Palæomutela*. In the Wankie coal-field^{6 10 37 58} the Lower Wankie

Sandstone rests directly on the Archaean gneiss. The Upper Wankie Sandstones contain an abundance of plant-remains, and it is remarkable that in this series of coal-bearing beds of Wankie there is a mixture of Northern, Indian, and Chinese forms. These coal-bearing beds are of Ecce age. The coal seams appear to be of drift origin, for there is no underclay. The flora^{5 8a} includes not only species of *Glossopteris* but also several species of *Sphenophyllum* and *Pecopteris* and *Cordaites hislopi*. Coalfields of probably the same age are the Lubu, Sengwe, and Mafungabusi to the north-east of Wankie, while in the far south-east of Rhodesia the small Tuli and Sabi coal-fields have more the Transvaal development of the Karroo System. In Northern Rhodesia there is the large Luano coal-field.

The **Madumabisa Shales** or **Upper Matobola beds** have a minimum thickness of 2000 ft., and consist of fine clayey sandstones, unstratified clays, sandy ironstones with *Estheria*, some limestones, and thin impure coals with *Glossopteris*. The upper part of the series is more calcareous, and contains large septarian nodules.

The **Escarpment Grits** are best seen at the south-western end of the Zambesi Basin, near Sengwe and Wankie on the south side of the river (see below), where they are more fully developed than farther north. Menell⁴ regards them as inseparable from the Forest Sandstones (see below). In the Luano, and near the Machinga escarpment of the Luangwa Valley, they dip north-westwards, and consist of a series of grits and hard red clays. In the Upper Luangwa Valley⁵⁵ the Stormberg Series is separated by an unconformity from the underlying Lower Beaufort beds (Madumabisa Shales). The Escarpment Grits form striking surface features both south and especially north of the Zambesi, and in their general character, except coloration, are like the Molteno beds.

The Somabula beds⁴⁵, on the Gwelo River, consisting of red arkoses and pebbles in which diamonds, rubies, topaz, and other precious stones occur, possess the distinctive characters of the Escarpment Grits, and contain plant-remains known from the Molteno and Red Beds of the Stormberg Series of the Union, such as species of *Thinnfeldia* and *Tæniopteris*.

The **Forest Sandstone**¹⁸ in Northern Rhodesia⁸⁹ has been recognised as a separate unit only on the Losito, where it occurs as fine-grained white, pink, or vermilion sandstones. In Southern Rhodesia, however, it has a considerable development north of Bulawayo¹⁸. It is considered to be of æolian origin, and much of it represents consolidated sand-dunes. The sandstones vary in colour from white to red, and the rock is much like the Bushveld Sandstone of the Transvaal. Dinosaurian remains have been found in it near Bulawayo¹⁹ and on the Limpopo⁸⁸, and the formation is referred to the Upper Karroo (Stormberg Series). North of Bulawayo it spreads northwards with a conglomerate at its base and calcareous sandstone and red false-bedded sandstone at the top, followed by the Batoka basalts in which sediments are locally interbedded.

The **Batoka Basalts** or **Volcanic Series** is immensely developed around the Victoria Falls and along the Zambesi Valley; it extends some 30 miles from the Zambesi into Northern Rhodesia³⁴, and southwards into the Kalahari Desert. Westward it appears to stretch a long way up the river, and Lamplugh⁶ describes it as cut off eastward by a great fault, but certain basaltic lavas intercalated with the 'Forest Sandstones' between Bulawayo¹⁸ and the Zambesi may represent it. The lavas of the Victoria Falls (Lamplugh's 'Batoka Basalts'), where five superposed flows are seen, are olivine dolerites,

and are mostly amygdaloidal⁸⁴. In thickness they must exceed 1000 ft. Intercalated breccias, varying from a few feet to 30 ft. in thickness, are found at the Falls. The extraordinary zigzag course¹⁰⁸ of the gorge below the Falls is due to the influence of structural planes or lines of weakness, such as joints and shatter-belts developed in the basalts^{44 84}. In the Tuli district and around Sabi the Volcanic Series is represented by basalts and limburgites.

(B) In NYASALAND the Karroo System is found^{23 40 98 100} at its northern end and along its south-western border.

(1) In the north it is found in isolated patches, often dropped down by trough-faults into the gneisses and schists; the beds have a prevalent dip to the east, though occasionally they are thrown into gentle folds. The series here falls into (i) an upper grit and limestone division; (ii) a middle shale, coal, and mudstone division; and (iii) a lower sandstone and basal conglomerate division.

The basal conglomerate rests directly on the gneiss, or has white or red sandstones below it, and is usually interbedded with sandstones. The coarse boulder-beds which occur in this division consist of large and small unsorted boulders and pebbles of granite and gneiss, either sub-angular or rounded, imbedded in a sandy matrix. No direct or unquestionable evidence of ice-action has been observed, as in the case of the corresponding basal Dwyka conglomerate farther south in the Transvaal and the Cape Province, but the stratigraphical correlation with it can hardly be doubted. The thickness of these beds amounts to 1300 ft. at Mount Waller, but to 2000-3000 ft. in the Luangwa Valley⁵⁵ to the west.

The middle division is about 200 ft. thick, and consists of dark shales, which are often carbonaceous, mudstones, grits, sandstones, and coal seams. The latter are usually lenticular, laminated and earthy, and the coal is of poor quality. But near Mount Waller the coals are purer and better. The typical Lower Gondwana plant *Glossopteris* has been found in them. The reptilian remains^{46 51 52} found in the down-faulted inliers of the Mount Waller and Fort Jameson districts point to the beds here belonging to the Beaufort Series (Middle Karroo). Reptile remains also occur in the Karroo beds of the Luangwa Valley^{32 55}.

The upper division is from 2000 to 3000 ft. thick, and consists of massive yellow and brownish grits and coarse-grained sandstones with lenticular seams of pebbles, and less often of shales and mudstones. In the extreme north-east corner of Nyasaland these beds are overlaid by a series of limestones and shales which seem absent elsewhere. The latter calcareous group in one locality (Nkana) attains a thickness of 150 ft., and at another place (Mpata) 700 ft., but farther south seems represented by arenaceous beds. The extreme rarity of limestones in the Karroo System makes this occurrence of much interest. In this set of beds (which is sometimes known as *Drummond's beds') there have been found fish-remains, including *Acrolepis* and *Colobodius*, and fresh-water lamellibranchs, such as *Palæomutela oblonga* Jones, which is a characteristic and widespread Karroo shell. Generally this upper division appears to consist of false-bedded felspathic grits, but in the Mount Waller area it is represented by 1500 ft. of mudstones.

(2) The Shire district of Southern Nyasaland^{23 98} has a completely different development of the Karroo System, and the beds are of great thickness, amounting in all to perhaps 20,000-25,000 ft., according to Mennell⁴. The beds are here continued without interruption to the Zambesi River, and across into the neighbouring Portuguese territory⁸¹, and are affected by some faults and gentle folds. Coarse boulder-beds, carbonaceous shales, and conglomerates appear to be the basal members of the sequence, together with a

series of sandstones, which are current-bedded and associated with pebble beds, forming a 'Lower Sandstone group,' 6000 ft. thick.

Above comes a 'Shale group,' including some sandstones, thin seams of coal and ironstone, and yielding several typical species of *Glossopteris* (*G. browniana*, *G. indica*) and other plants, with perhaps a thickness of 4000 ft. An 'Upper Sandstone (or grit) group,' composed of massive sandstones, frequently pebbly, and of grits, has a probable thickness of 10,000 ft. This is succeeded by a 'Lava group,' 5000 ft. thick, consisting mostly of vesicular basalts, with some andesites and banded rhyolites and interbedded sandstones, but no tuffs. The Upper Sandstone and Lava groups correspond to the Stormberg Series of the Cape and Southern Rhodesia³⁴. They also represent parts of the Forest Sandstones of Northern Rhodesia. Pebbly sandstones close the sequence in the adjacent Portuguese territory.

Igneous Rocks of Doubtful Age

Rhodesia.—It is probable that some of the coarsely crystalline intrusions in the Archaean rocks of Rhodesia belong to the pre-Karoo and others to the post-Karoo period. The coarsely crystalline basic intrusion and associated rocks which extends as a huge mass across nearly the whole of Rhodesia from south to north is one of these. It has an outcrop about four miles wide at Lomagundi and elsewhere, and is probably a gently-inclined sheet or dyke injected along a thrust plane. According to Mennell⁴, it is of later date than the granites but pre-Karoo.

According to Zealley, this so-called 'Great Dyke'^{83 90 101} of Southern Rhodesia^{18 36 59}, which is well seen in the Belingwe and Selukwe districts, comprises a series of rocks ranging from norite through pyroxenite and harzburgite into pyroxene and felspar-free-olivine-rock, which is usually completely serpentinised.

It is probable that its intrusion may be of the same date as some rocks of the Bushveld Plutonic Complex, for it has the same complex composition and cuts through the Basement formation. It has a width of from two to eight miles and is traceable for over 300 miles. Its economic importance lies in the layers of 'chromitite' which dip inwards on either side of the dyke¹⁰¹. It has been suggested⁸³ that its formation is connected with the rift valleys of East Africa, its course indicating a rift. The dunite-serpentine complex of ultrabasic rocks in the Shabani district⁴⁵ which invades the Basement schists, and is itself penetrated by a gneissic granite, is earlier than the Great Dyke and the other dolerite dykes and sills in that area. In Northern Rhodesia the igneous rocks in the Abercorn and Kasama districts⁷² are mostly pre-Kundelungu and include granites of several types, gabbros, and other basic rocks, some of which pierce the Kundelungu Series. But no Karoo or post-Karoo intrusive or volcanic rocks have been described here. Rocks of the same type as those of the Lebombo Mountains extend from them into the south-eastern part of Southern Rhodesia⁹², and include basalts, rhyolites, granophyres, etc., of pre-Cretaceous but Karoo age.

The gabbros and dykes of ophitic dolerite which are especially common in the central portion of the country are probably of the same general date and origin as the above-mentioned Great Dyke. Some of the dolerites traverse the granites and thus prove their age to be subsequent.

Diamond-bearing deposits, one of which undoubtedly fills a volcanic pipe and is of the same type as those at Kimberley, are known about 40 miles

* According to Dana, so-called 'chromitite' (FeCrO_3) is but a mixture of chromite with magnetite or haematite.

north-east of Bulawayo. The walls of this pipe are of granite, but the rock-fragments and blue ground have the general character of other similar occurrences in South Africa. The age of its formation is probably the same as the age of those described at Kimberley and other places in the Union of South Africa. Kimberlite also occurs in fissures in the Bembesi and Shangani Valleys²⁴.

Cretaceous.—It is only in Nyasaland^{40 54 69 73 100} that beds of this age have so far been found. On the north-west side of Lake Nyasa there are long strips of Lower Cretaceous beds^{23 40 51 52 55} of fresh-water origin faulted in amongst the older rocks and containing dinosaur⁵¹ and chelonian remains⁵². These beds are apparently a continuation of the *Tendaguru* beds of the Tanganyika Territory (see p. 80). They consist of fresh-water thick-bedded reddish and purplish grits and sandstones followed by alternating white sandstones and red clays, occurring in several parallel strips from Florence Bay almost to the Songwe River. In southern Nyasaland they are represented by the Lupata Sandstone⁹⁸.

Tertiary and Later Sedimentary Deposits

Nyasaland⁴¹.—During the earlier stages in the development of the Lake⁷³ this series of sediments⁴¹ was deposited in its waters, and it rests on the worn edges^{54 69 100 102} of the Dinosaur beds. The deposits occupy now the floors of several minor rifts parallel to the main rift valley. The oldest, or Sungwa, group of beds, consisting of thick-bedded sandstones and conglomerates, is perhaps of *Miocene* age, and rises to a height of 1000 ft. above the lake. The next group comprises a thick series of calcareous sands, marls, and limestones which have yielded remains of *Mastodon* and *Hippopotamus*¹⁰⁷ with fresh-water shells and are referred to the *Pliocene*. They rest unconformably on the Miocene beds. The succeeding group consists of the Chitimwe red conglomerates and gravels. Next come the Songwe volcanic tuffs and ashes, 250 ft. thick, but only at the north end of the lake; and finally come gravels traceable almost all round the lake at a maximum height of 400 ft. Recent deposits⁴¹, including the youngest lacustrine sediments, occur up to a height of about 160 ft. above lake-level. All the groups are mutually separated by unconformities. Recent fluctuations of the lake are related to the rainfall¹¹⁰.

Volcanic Rocks.—Tertiary⁴⁰ 72 73 109 and Recent lavas, connected with low volcanic cones, have a great development at the north end of Lake Nyasa, but lie across the frontier in the Tanganyika Territory. There are two volcanic masses at this point where the Rukwa and Ruaha troughs diverge respectively to the north-west and north-east. One mass is formed by the Poroto ridge and the other by the lofty Mount Rungwe and its associated cones^{101 109}, which lie just beyond the frontier of Nyasaland. Fragments of volcanic tuff-deposits, however, occur in Nyasaland, near Nkana, and the hot springs at Mount Waller and elsewhere along the line of the lake probably mark the last stages of volcanic activity. Hot springs are also common throughout Northern Rhodesia¹⁴, and seem associated with lines of fracture and sunken areas, as, for instance, east of Lake Mweru, along the Luano subsidence, and along the Luangwa valley-trough. Siliceous sinter and calcareous tufa are frequently deposited by them. Similarly the northern part of Southern Rhodesia is characterised by the prevalence of mineral springs, mostly thermal, and some saline or siliceous; they vary from steam-jets and fumaroles to mere percolations of saline water. They are associated with the volcanic rocks, and have frequently deposited siliceous sinter which has cemented together the

loose surface-sands, enclosing shells of recent land and fresh-water mollusca and silicifying tree-trunks.

At the south end of Lake Chilwa⁸², south-east of Lake Nyasa, there are two volcanic vents from which rhyolitic lavas and ashes have been poured out, followed by the intrusion of nepheline-syenite and finally by ultrabasic dykes like those piercing late Tertiary sediments on the Sheringoma plateau.

Loose or feebly consolidated red or white sands (the Kalahari Sands¹⁸), surface-quartzite⁶, tufaceous limestone and laterite^{9 15} or lateritoid¹⁸ are found over wide areas in Rhodesia, and are mostly the products of weathering or wind-action. The Kalahari Sands may reach a thickness of 100 ft. The Kalahari beds at and around the Victoria Falls have yielded mammalian remains including those of several species of elephants^{86 107}. Maufe⁸⁵ has correlated the Kalahari beds at the Victoria Falls with those of the Kalahari Desert as classified by Passarge, and his 'Pipe Sandstone' is considered to correspond with Passarge's Group B, and to be separated above and below by unconformities with the other surface deposits. The Pipe Sandstone has yielded a few plant-remains (*Chara* sp.) and fresh-water shells.

The gem-gravels and associated sands of the Somabula Forest^{20 24 45}, about 12 miles S.W. of Gwelo, reach a thickness of about 150 ft., and yield diamond, ruby, sapphire, topaz, and many other precious stones. (See * Economic Geology.)

EARTH-MOVEMENTS AND TECTONIC FEATURES^{9 4}

Several periods of folding are recognisable in this area, and more than one period of faulting has been determined. The movements prior to the deposition of the Transvaal System seem to have produced folds with a general north-easterly strike, and the post-Transvaal System folding seems to have been along the same lines. This latter movement took place before the deposition of those sandstones and other rocks which are possibly referable to the Waterberg System, and a long period of erosion⁵⁶ occurred in the interval.

The next folding took place in post-Karoo times and was very gentle; in Northern Rhodesia the Karroo beds were thrown into a series of anticlines and synclines by a force acting from the south or south-east. But the main post-Karoo movements were not of the nature of folds but of fractures or dislocations on a huge scale, and these took place at more than one period. The earlier faulting formed the troughs trending from north-east to south-west, and it is in these that the Karroo beds are preserved, strips or blocks of the Karroo beds being dropped down into the basement gneiss⁴⁰. The later meridional troughs were subsequent to the removal by erosion of the Karroo beds from the intervening areas¹⁴. The Deka fault³⁷, which cuts off the basalts of the Zambesi on the south, the Maohinga fault which runs on the north side of the Luangwa Valley⁵⁵, and other parallel fractures, belong to the early set of movements. The middle Zambesi Valley below the Gwaai confluence is regarded by Studt¹⁴ as an area of subsidence practically continuous with that of the Luangwa Valley, which runs

north-east towards the north end of Lake Nyasa. Step-faulting along the escarpments is a characteristic feature. The course of the Zambesi eastwards from Feira also appears to lie along a sunken area.

The formation of the axis of the huge anticline which runs through Rhodesia from south-west to north-east and brings up the Archaean rocks, throwing off the Karroo beds in a great synclinal towards the Zambesi on the north, was also a result of the early post-Karoo disturbances. The evolution of the Congo basin to the north-west of Rhodesia is due to these earth-movements". It is deserving of notice that the direction of these faults and folds agrees with that of the foliation and cleavage in the older rocks and with the axes of elevation of the earlier pre-Karoo movements.

The post-Karoo earth-movements were followed by an early Cretaceous uplift in one or two stages and resulted in a long period of erosion¹⁰² and peneplanation⁶⁹. The Zomba and Mlanje plateaus belong to this peneplain⁵⁴. The beginnings of the rift valley of Lake Nyasa occurred before the deposition of the Dinosaur (Cretaceous) beds which filled it in during a period of depression. In late Miocene times there was a general uplift, and the second main peneplanation took place. In the interval between the formation of these two peneplains considerable movements occurred, not of an orogenic nature but resulting in vertical displacements and faulting. The chief rifting and formation of the present Lake Nyasa¹⁰⁰ trough took place in post-Miocene times and has gone on intermittently with tilting and warping of the beds. But the amount of depression of the floor of the valley varied. Where the lake is deepest (2200 ft.) its floor is 700 ft. below sea-level⁷³. Minor parallel faults have been formed at different times, so that not all parts of the rift valley are of the same age. The Cholo fault¹⁰⁰ seems to be of late formation. The movements resulting in the formation of the peneplains do not appear to have similarly affected the whole area and, as mentioned, the longitudinal faults¹⁰⁰ bounding the rift valley originated at different times and do not all have precisely the same trend¹⁰⁰. At the south end of the lake there is a cross set of faults trending N.N.E.-S.S.W. and bounding Lake Chilwa and the Upper Shir6 river valley; at the north end of Lake Nyasa there is a strong divergence of the two fault-trends passing into the east and west rift-valleys, as described in the chapters on Tanganyika and Kenya¹⁰⁹. In Northern Rhodesia Dixey¹¹⁵ has described more than eight erosion surfaces, the later ones constituting definite peneplains. The chief peneplains which he recognises are : (1) the late Jurassic at heights of 7000-7500 ft.; (2) the late Cretaceous at 5200-5500 ft. ; (3) the middle Tertiary (Miocene) at 4200-4800 ft.; and (4) the end Tertiary at 3000 ft.

The faulting of the Nyasa region^{40 54 56 69 73 100 109}, which resulted in the formation of the present lake-trough, is mainly meridional in direction and of later date than the north-east to south-west fractures. For the longitudinal dislocations truncate the transverse faults, as may be seen in the Ruhuhu area. It is noticeable that the only case where the trough-valley of the lake holds Karroo beds is where it crosses the north-east to south-west subsidences, and at such a place of intersection the beds are much disturbed. Some of the longitudinal lake-faults seem to have been the last of the series of movements and dislocations which broke up the old plateaus, and their comparatively recent formation and the late origin of the lake are shown by a certain sharpness of the edges of the plateau, and by the shortness of the lateral streams on the eastern side, as well as by the absence of large deltas^{15 23}. Successive stages in the size and depth of the lake are traceable by the series of Tertiary and post-Tertiary lacustrine deposits round its edges⁷³.

In the East African region farther north we have seen that at least three different directions of fracture are traceable and that the meridional faults were likewise the latest. The set of earlier faults in the Nyasa district which broke up the Karroo beds agrees in general direction with the so-called Somali group of dislocations in the northern region.

ECONOMIC GEOLOGY^{40 91 95 105}

Coal¹⁰.—Of primary importance are the coal-deposits, all of which belong to the Karroo System. The main coal-belt in Rhodesia can be traced from a point about thirty miles west of Wankie eastwards through the Sebungwe, Bubi, Mafungabusi, and Lomagundi districts to Tete in the Zambesi. The Wankie^{37 58} coal-field lies about 68 miles south-east of the Victoria Falls, and is cut off abruptly to the north-west by the Deka Fault. The coal occurs in seams varying from 6 ft. to nearly 40 ft. in thickness, which thin towards the east, but are thickest towards the west. The percentage of ash is from 6 to 15 per cent., and the coal must be placed in the semi-bituminous class. The beds dip away from both sides of a ridge of schists which traverses the field.

On the north side of the Zambesi is the large Luano coal-field, over 500 sq. miles in area. In addition to these there are the Tuli coal-field on the Limpopo, and the Sabi coal-field on the Sabi River.

The majority of the Rhodesian coals contain a high percentage of ash when compared with British Carboniferous coals.

In Nyasaland^{112 40} there are coal-seams in the Karroo beds of the Nkana area on the Songwe River at the extreme north of the province, at various localities (*e.g.* Kasante) near the west end of

the north end of the lake, and in the Mount Waller area farther south, where the coal is superior to any in Nyasaland, and three seams are known. In the lower Shire area good bituminous and anthracitic coals have also an extensive development. But in Nyasaland generally the coals are variable in quality and the seams thin.

Asbestos^{40 59}.—The chrysotile variety is abundant in the Shabani^{49 111} and Victoria districts in connection with altered ultrabasic intrusions, and the hornblende variety occurs in the Tuli district. In the Umvukwe Range⁵⁹ it occurs as veins in the serpentine along the edge of the Great Dyke.

Building Stones.—The chief building stones in Rhodesia are obtained from the 'Forest Sandstones,' but the granite of the Matoppo Hills has also been a little worked. In Nyasaland the granite of Likoma and the 'soap-stone' of Lake Nyasa have been used locally.

Gem-stones¹⁰⁵.—The diamond-bearing gravels of the Somabula Forest⁴⁵ rest with a great unconformity on the weathered surface of the granite and are of fluvial or estuarine origin. They occur at the base of each of the two groups of Karroo beds of Stormberg age, the lower group consisting chiefly of mudstones with fine pink sandstones, and the upper group of coarse red feldspathic sandstones or arkoses. Almost 90 per cent, of the pebbles in the gravels consist of quartz. A great variety of minerals occur in them; chrysoberyl is the commonest gem-stone, but topaz occurs and corundum is represented by rubies and sapphires, and tourmaline is abundant. The diamonds are mostly small; probably they came from the kimberlite pipes in the Bembesi-Shangani area²⁴.

Gtolfi^{36 38 89 48 49 61 63 64 66 68 74 - 77 91 93}.-----In Rhodesia gold OCCURS

under various geological conditions in the pre-Karroo rocks; but it is found chiefly as reefs and impregnations or as replacement-deposits in shatter-belts in the basement schists, in the epidiorites, in the banded ironstones, and in the conglomerates³⁸. The Eldorado Banket^{30 104} was at first believed to be similar to that on the Rand, but it is now regarded as distinct, the gold occurring either as films along schist planes or in cracks in the pebbles of the conglomerate³⁸. The reefs are auriferous quartz-veins, in the form of fissure- or gash-veins, and they usually traverse the metamorphic rocks. The impregnations, which comprise the majority of the deposits which are worked, include impregnations of granulite and granite, as well as of the rocks above mentioned. The gold-deposits are for the most part closely related²¹ to the acid intrusives, but in the Lonely Mine⁴⁸ north of Bulawayo they are related to the limburgite, greenstone, and

serpentine intrusions where such are altered to schists. In the Cam and Motor Mine¹¹¹ the reefs occur in the sharply-folded schists enveloped in later granite. The Phoenix ore-body in the Globe and Phoenix Mine consists of a complicated system of quartz-filled fissures in the schists and granite¹¹¹.

Copper.—The copper deposits of Northern Rhodesia^{43 65 67 68 78 79 91 96 97 112} occur in the equivalents of certain pre-Karoo beds of the Transvaal, as is also the case in the Katanga¹¹⁴ district to the north of the Rhodesian frontier. The Northern Rhodesian^{43 51 52 65 67 68 70 78 79 91 95 96 97 105 109 112} copper belt lies on part of the great plateau and closely similar geological conditions prevail throughout it. The ores occur in the so-called Katanga System⁹⁷ which lies above the unconformity which follows the Basement schists and the older granites, etc., intrusive into them. The 'host-rock' of the copper is known as the *Roan* or *Bwana M'Kubwa Series*, consisting of conglomerates, arkoses, shales, sandstones, and dolomites, and forming the lowest member of the Katanga System^{97 109}. None of the thick series of overlying quartzites, sandstones, and shales, amounting in all to about 15,000 ft., contains copper. Amongst these beds is a conglomerate which may be of glacial origin. A grey granite in the form of an eroded batholith with pendants of sedimentary beds and cupolas of granite invades the series and is supposed to be responsible for the mineralisation. A later intrusion of red granite and of basic sills is also present. The ore occurs along bedding planes of the Sedimentary Series¹, or as saddle-reefs or along shear or shatter zones or in fissures in the granite. Cobalt is associated with the copper ores. The sedimentary rocks have been folded into a series of asymmetric anticlines and synclines with their axes trending generally to the north-west and plunging in the same direction. The folds are generally simple. The ore-deposits, which are of epigenetic origin, all lie within 1500 ft. of the base of the Roan Series and consist of one or more beds mineralised by minute particles of copper sulphides (but some are oxidised) which have been introduced by metasomatic replacement⁷⁹ of the original minerals (silicates, etc.). The ore-bodies all occur near granite intrusions. The beds^{43 51 65 67 78} in the Katanga and Rhodesian areas show a generally close agreement, but in the Katanga the copper deposits are chiefly oxidised ore-bodies near the surface with malachite as chief ore mineral, while the sulphide ore-bodies of Rhodesia lie stratigraphically lower in the series. At Kansanshi the strata form a hill with qua-quaversal dip; and the ore-deposits occur in long parallel perpendicular fissures. In the Bwana Mkubwa area the beds are vertical as well as the ore-bearing fissure, so that the deposit seems to be interbedded. In the Sabi

district the cupriferous beds are considered to be of Waterberg age, and the ore is of the nature of an impregnation.

Iron.—Haematite and limonite occur as interbedded deposits, often associated with manganese, in the banded ironstones (itabirites) of the Dolomite Series, and are frequently traceable for long distances. Large irregular deposits are also found in the same rocks.

Lead and Zinc are found in irregular pipes filled with dolomitic breccia in the Lomagundi (Transvaal) System of Broken Hill¹¹², Rhodesia. The zinc-blende is found associated with the galena in irregular masses and as impregnations in the crystalline limestone ; it is much oxidised at the surface.

Chromite.—The chromite deposits of Selukwe^{17 59} occur in the talc-schist and serpentine group of the ancient metamorphic rocks. The chromite is found in masses or lenticles ranging from a few feet to several hundred feet in width and length, the trend of the bodies and the strike of the foliation commonly coinciding. Chromite also occurs at Selukwe in thin seams in the later intrusion known as the Great Dyke⁵⁹.

Platinum.—In the Great Dyke⁸⁷ of Southern Rhodesia, which stretches for 300 miles with a width of 3-4 miles, platinum has been found in some localities and, from the similarity of the rocks composing the Dyke to those of the norite zone of the Bushveld Complex, it is probable that the magma was similar and the time of intrusion contemporaneous. It is probable that the platinum in the Soma-bula⁴⁵ conglomerates near Gwelo was derived from the same source.

Bauxite^{40 103}.—There is an important deposit of bauxite on the Mlanje Mountains⁴⁰ in Nyasaland, extending over an area of not less than 2 sq. miles, and in parts exceeding 40 ft. in depth. It has been formed in place by the alteration of the underlying rock which is an orthoclase-hornblende syenite.

Vanadium.—In the Broken Hill mines this mineral is found associated with the zinc-lead ores.

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CHAPTER V

SOUTHERN AFRICA

SECTION I.—UNION OF SOUTH AFRICA

(INCLUDING BECHUANALAND, SWAZILAND, AND BASUTOLAND)

General Geological Characters^{163 194 259 269 310}.—The greater part of South Africa belongs structurally¹ to the great African plateau of ancient rocks which extends from the Sahara in the north to the Cape Province in the south, and stretches across the breadth of the Continent from east to west. It is a fragment of a larger land-mass which has sunk on each side along gigantic fault-lines or monoclinal flexures¹⁹⁴ so as to form the Atlantic and Indian Oceans. It constitutes, in fact, a surviving portion of the former great Indo-African continent or 'Gondwanaland',^{130 249 309} which has never, so far as we know, been completely covered by the sea since the end of the Pre-Cambrian times, though portions have undergone marine transgression during late Palaeozoic, Mesozoic, or Tertiary times. Nor has South Africa suffered more than marginal or local folding movements of minor importance since the close of the Palaeozoic period. South Africa indeed structurally constitutes a foreland against which marginal arcs of folding^{200 201} have advanced from the south-west and probably also from the east, forming folded marginal ranges which are described below.

Two more or less distinct geological and physiographical³⁰³ provinces or divisions may be recognised in British South Africa :— (1) a southern one consisting of a great inland plateau-region together with a marginal belt of folded mountain ranges²⁹¹ and a narrow coastal band lying between the latter and the sea ; and (2) a northern one without any fold-mountains, comprising most of the Transvaal and Orange free State, the northern part of the Cape Province and the Bechuanaland Protectorate. Farther north, Southern Rhodesia belongs also to this province. This second division seems to have had a somewhat different early geological history, and the succession and development of the older rocks which occur in it are not at present satisfactorily brought into correlation with those in the southern division. But the two provinces have one feature in common, *i.e.* the fact that there is no evidence that either of them has sunk below sea-level or received

on its surface any marine deposits since Palaeozoic times, except along narrow marginal strips of the coast. **The** topographic features²⁸⁸ of the whole country are partly the result of a series of earth-movements, which have not been of an orogenic character since Palaeozoic times, have been chiefly produced by faulting **and** long-continued sub-aerial denudation since the beginning of **the** Jurassic period. But Demay²⁰¹ recognises three principal orogenic periods in South Africa, the first of which was pre-Witwatersrand, the second post-Witwatersrand (but ante-Devonian), and the third post-Devonian (but pre-Karoo) corresponding to the Hercynian of Europe. Hennig²⁸⁹, Krenkel^{194 310}, Born²⁰⁰, and others have elaborated the various movements and given them distinctive names. Together with the rest of South and Central Africa, the area of the Union has passed through several erosion cycles²⁸⁷, **as** Dixey has pointed out.

The first division or southern part of the Union, comprising the greater portion of the Cape Province, the Orange River Free State, most of Natal, and the southern portion of the Transvaal, consists of a mass of pre-Devonian and Devonian rocks forming a structural 'foreland,' and overlain unconformably by a series of mostly horizontal younger rocks, ranging from Upper Carboniferous to Jurassic and known as the Karroo Formation, which is of primary importance and wide extent. The marginal belt consists of considerably disturbed old crystalline and Palaeozoic rocks which have been thrown into numerous parallel folds and are traversed by longitudinal faults, both of them more or less parallel to the present coast-line. These rocks surround the plateau-region on the west, south, and east, except where the ring is broken between the Great Fish and St. John's Rivers on the east coast^{194 200 201 202}.

There are three main sets of folds affecting these rocks, of **which** the first set is made up of those in the west, represented by the Cedarbergen and trending N.N.W. so as to meet the second set near Worcester in a syntaxis. This second set is represented by the Zwartebergen, in which the folds run nearly at right angles to the first set, and by meeting a third set they probably form a second syntaxis beneath the sea at their south-east end. This third set forms the Pondo Mountains, and is found also in Natal running N.N.E.

Of later date than the Karroo Formation there are no **beds** in the interior except superficial deposits. But near the coast **on the** south and extending up the east coast beyond Natal into **Zululand** and Portuguese territory, there are a few patches of Cretaceous **beds**, **and** these constitute the narrow coastal belt. A few small **deposits** of marine origin and of Tertiary age occur on the west coast¹⁹⁶ **and** in the south-eastern districts of the Cape Province¹³³.

The second division or northern part of British South Africa is chiefly composed of old crystalline rocks of much earlier date than the Karroo Formation, which is only represented here by isolated fragments and faulted inliers, but probably had a wide extension over the surface previous to its denudation. In this region the old pre-Karoo rocks have been thrown into many folds and are much disturbed and faulted, but the general trend of the folds (though some belong to different and post-Archæan periods) is from E.S.E. to W.N.W. In some cases minor earth-movements took place as late as Cretaceous or even Tertiary times, and affected beds of those periods.

There are thus seen to be present in South Africa three chief groups of formations which may be designated the pre-Karoo rocks, the Karroo rocks, and the post-Karoo rocks, the Karroo Formation being the most distinctive in the country.

The pre-Karoo rocks include all the earlier or pre-Permo-Carboniferous Formations. A small part only of them is fossiliferous and this only occurs in the Cape Province; all the others are either crystalline and metamorphic in character, or of igneous origin, or composed of unaltered sediments which are devoid of organic remains, so that the correlation of the rocks in different isolated areas or with the European systems is a matter of uncertainty. It is these pre-Karoo rocks which extend northwards over immense areas into Central and East Africa, and north-westwards into South-West Africa, though with diverse facies and types of development.

The post-Karoo rocks are confined to the marginal and coastal regions chiefly in the south and east (with the exception of the Pleistocene and Recent superficial deposits), and the evidence indicates that they never were spread over the interior. The most interesting of the marginal formations are the patches of Cretaceous beds.

In the present state of our knowledge it is convenient to describe the complicated and varied series of pre-Karoo rocks of the southern province apart from those of the northern parts of British South Africa²¹¹⁶. The diverse nomenclature^{163 247} which has been introduced has obscured their correlation, and it is difficult in the face of rival opinions to attempt a general description. Since, however, the Karroo rocks themselves have a comparatively uniform type of development over the whole Union, they need not be independently treated for the two provinces, while the post-Karoo rocks, being either limited to the coastal areas, or having generally similar characters over both provinces, can also be described together.

The physiography and development of the surface features of

South Africa have been described and discussed by Davis²⁹¹, and others^{163 164 194 202} but especially by Dixey^{214 287}, and more recently by King²⁸⁸.

DETAILS OF THE STRATIGRAPHY

Pre-Karoo Formations

1. Southern Geological Province

The pre-Karoo rocks in this province lend themselves to description under two divisions. These divisions are based on relative age and comprise (a) the complex of crystalline, metamorphic, igneous, and sedimentary rocks without fossils, and (b) the overlying beds forming the so-called *Cape System* of which certain beds are fossiliferous. The older division, which may therefore be called the *pre-Cape Group*, consists not only of several definitely successive series of rocks, but also includes many geographically isolated and local developments of beds with local names, the precise age and correlation of which are at present undetermined. All the pre-Cape rocks, however, agree in having suffered intense disturbance and denudation, and often considerable alteration before the deposition of the Cape System, the beds of which rest unconformably on them.

Pre-Karoo Formations	{ Cape System	{ Witteberg Series.
		{ Bokkeveld Series (=Lower Devonian).
		{ Table Mountain Series.
	{ Pre-Cape Group	{ Nama System (various local series).
		{ Fundamental Complex {

(a) Pre-Cape Rocks.

Distinctive names have been applied to the many local developments of these rocks, and their correlations and order of succession have only been satisfactorily settled in a few cases. It is probable that they represent many chapters of Archaean and Pre-Cambrian history. Till recently the oldest known rocks in the Cape Province were believed to be the so-called *Malmesbury Series* (see below), but Rogers^{8 9 10 11} and others have shown that there exists a still older complex of sedimentary and igneous rocks, mostly metamorphosed, forming the basement on which these and subsequent formations were laid down. The pre-Cape rocks are therefore divisible into an older series or *Fundamental Complex* and a newer or *Nama System*, which includes the Malmesbury beds.

(1) Fundamental Complex or Pre-Nama Rocks.—These rocks occupy a large area north of Van Rhyn's Dorp and spread over much of Namaqualand⁷⁸, beyond which they extend far into South-West Africa. A great variety of lithological types is represented in this group, comprising gneissoid and granitic rocks, schists, metamorphosed sediments and igneous intrusives. Of the gneisses which are of more than one mode of origin, a well-foliated gneiss containing perthite is one of the most abundant and characteristic

types, and granitic biotite-gneisses are also common. Crystalline limestones and marbles occur in bands, and granulites are often intercalated. Altered lavas are also found in some places. The original foliation of the rocks strikes east and west, but near the coast it has been changed by subsequent movements to north and south. Granites and other igneous rocks of more than one period of intrusion have invaded this complex in pre-Nama times, and have produced alteration in the surrounding rocks.

According to recent work^{163 247} on the rocks of the Fundamental Complex, the older part, which is known as the *Swaziland System*, includes the *Kheis Series* and *Kraaipan Series* in the Cape and Bechuanaland respectively. The '*Kheis Series*'^{40 69 78 91} extends as a broad belt running S.S.E. from the neighbourhood of Upington into the Prieska division, and has been divided into three groups, of which the lowest consists of hornblende- and pyroxene-schists, granulites, gneiss, quartzite, various phyllites, mica-schists, limestones, and schists resulting from the metamorphism of various lavas and volcanic rocks. The lavas range from acid to basic in composition. There are also intrusions of serpentine and granite. The middle group consists chiefly of quartz-schists, with layers of granulite; masses of granite have invaded them. The third and uppermost group consists of sheared lavas, often amygdaloidal, tuffs, conglomerates, limestones, etc. The relations of the three groups are rather uncertain owing to the complicated disturbances which they have suffered and to the amount of folding and crushing which they have undergone. Their thickness is considerable, but cannot be at present estimated. The Campbell Rand Series⁴ (see p. 134) rests upon them unconformably. The *Kraaipan Series* in the Mafeking district is described in connection with the Northern area (see p. 127).

Large tracts of country are occupied in Prieska, Kenhardt⁷³, and Gordonia by granite and gneiss, which are probably referable to the *Swaziland System*, while in Bechuanaland granite or gneissose granite of possibly the same age covers thousands of square miles; some of the granites in these regions are certainly of later date, though their precise age and relations have not been determined in all cases.

(2) **The Nama System** in the Cape Province comprises three series of rocks, of which the *Nieuwerust* is the oldest, the *Malmesbury* the intermediate, and the *Ibiquas* the youngest.

The *Nieuwerust Series* consists of arkoses, quartzites, and rarely hard shales. The quartzites are often false-bedded and ripple-marked and, where the series rests on the ancient gneisses and schists, contains fragments of quartzites and large boulders of the underlying rocks (granites, gneisses, etc.). In thickness it varies from 200 to 500 ft. It occurs in outliers or forming plateaus in the Van Rhyn's Dorp division, and extends northwards to the Orange River, but has not been found south of the Olifant's River. In Northern Namaqualand there is a remarkable deposit 800-1700 ft. thick, known as the *Numees tillite*^{125 276 299}, which lies under the Kuibis quartzites of the *Nieuwerust Series*, and contains boulders of gneiss, granite, limestone, etc., showing glacial striations. It is invaded by the Koboos granite²²¹, which has caused much contact-alteration. This series of beds is specially developed farther north in South-West Africa (*q.v.*) in the Great and Little Kharas Mountains, and rests on older gneisses and crystallines with a strong unconformity. It has been correlated with²⁴⁷ the Ventersdorp System (*q.v.*) of the Transvaal, which is one of the Pre-Cambrian formations in the northern Province, but **this** reference is doubtful. The *Malmesbury Series*, in Van Rhyn's Dorp, Malmesbury, Paarl, etc., appears below the Table Mountain Sandstone and consists of shales, flagstones, argillaceous quartzites, and especially limestones, which

are here considerably developed, and are black or brightly coloured. Farther south, the calcareous beds become less important, and the most abundant rock is stated to be a blue arenaceous clay-slate or very fine-grained argillaceous quartzite. Still farther south the rocks have been altered into phyllites, andalusite-schists, mica-schists, etc., and occupy the greater part of the divisions of Malmesbury, Piquetberg, Paarl, Stellenbosch, and Somerset West. A strip of Malmesbury beds occupies the Tulbagh Valley, stretching south-east past Worcester to Swellendam. In Mossel Bay, George, and near Port Elizabeth⁸¹⁸, rocks of similar character occur, but here the strike has swung round so as to assume an east-and-west direction. Structurally the beds mostly occur in isoclinal folds. In the Uitenhage division³³⁵ the pre-Cape rocks consist of sedimentaries including some dolomitic limestones and are usually referred to the Malmesbury Series; the quartzites at the top are said to pass up into the Table Mountain Sandstone without any apparent unconformity. The Malmesbury beds of the Cape have been correlated with the Transvaal System of the Transvaal.

There are certain younger gneisses, especially granitic gneisses, which are mostly intrusive in the Malmesbury beds. These occur in Van Rhyn's Dorp division, in the Moed Verloren Hills, and on the coast of Namaqualand¹¹. These are of post-Malmesbury or probably post-Ibiquas age (see below), and cover large areas. They were formerly confounded with the older (*i.e.* pre-Nama) gneisses.

In the southern part of the Cape Province also there are several large masses of granite, frequently gneissic in character, and having elongated outlines with their longer axes parallel to the strike of the beds, and these intrusions are certainly later in date than the Malmesbury rocks. The largest of these intrusions is the mass of granite which extends S.S.E. from St. Helena Bay for 70 miles, and is locally foliated. Another mass underlies the sandstone of Table Mountain, and another is found in the Paarl district. In the George Division the granite intrusion measures about 30 miles in length and 4-8 miles in breadth. Quartz-porphyrries, microgranites, and pegmatites occur as apophyses of the granites or independently, and dykes and masses of more basic intrusive rocks, such as diorite, are found in some localities. Two or three distinct periods of these intrusions of igneous rocks can be distinguished.

The *Ibiquas Series* is typically developed in the Van Rhyn's Dorp division, and consists of conglomerates, grits, sandstones, shales, and slates, considerably disturbed and folded in the west, but almost horizontal towards the east. Their thickness must amount to several thousand feet. The Table Mountain Series of the Cape System overlies them unconformably. The conglomerates contain pebbles and boulders evidently derived from the Malmesbury beds and from granitic intrusions, and rest unconformably on these beds. Only ripple-marks and 'worm-casts' have so far been found in the Ibiquas Series.

A peculiar series of beds known as the *Cango Series*²¹⁸ occurs in the Oudtshoorn district of the Cape Province on the south side of the Zwartebergen, forming a rough lenticular mass about 70 miles long from east to west. The beds of the Cape System rest unconformably upon them. The series is not less than 10,000 ft. thick, and is thrown into isoclinal folds dipping southwards. It is composed of conglomerates, quartz-felspar grits, quartzites, dolomitic limestones and slates, and all these rocks are pierced by dykes of diabase. The conglomerate consists of large pebbles or boulders of quartz, quartzite, slate, granite, etc., imbedded in a chloritic matrix, and is frequently sheared. The quartz-felspar grit seems to be an arkose. The limestones are sometimes of great thickness, and in one of them are the famous Cango Caves^{20 218}. By Mennell and some others this series is correlated with the later Dolomite Series of the Transvaal System in the northern province (see p. 134).

The Nama System extends into the South-West Africa Protectorate, and there it has a wide development (*q.v.*). We may with great probability regard it as equivalent to the more fully known 'Transvaal System' of the northern part of the Union, which till recently was thought to be absent from the Cape Province.

The correlation of the Upper Pre-Cambrian formations in the whole of Southern Africa, including those in the Union, South-West Africa, and Rhodesia, has been attempted by means of the lead-ratios³¹⁵ with satisfactory results.

(b) The Cape System.

Resting discordantly on the various older series of rocks in the southern geological province, but apparently (see below) absent from the northern province, is a group of formations termed the Cape System. It consists of a thick and varied succession of sandstones, grits, quartzites, shales, and mudstones, and is partly fossiliferous, yielding the oldest definite organic remains in South Africa. Part of it at any rate is of marine origin. Where it is fully developed it is divisible into three series, and these are conformable to one another. The lowest series is known as the *Table Mountain Series*, the middle one is the *Bokkeveld Series*, and the upper is the *Witteberg Series*. The system is developed in the marginal or folded zone of the southern province, and stretches from Van Rhyn's Dorp in the west southwards to Cape Town, thence bending eastwards to Port Alfred and the Great Fish River, where the zone is interrupted till we come to St. John's River, north of which it spreads out as a wider band (but incompletely developed) into Natal. The beds are usually thrown into a series of simple saddles and troughs, the axes of which are generally parallel to the coast-lines. Most of the anticlines are marked by a topographic ridge of Table Mountain sandstone, while the Bokkeveld and Witteberg beds form only the lower slopes. The dominant strike of the folds has determined the main outlines of the land margins. The folding movements, however, were repeated along the same general directions in this marginal zone during and after Karroo times (see below). Du Toit^{163 277 307} has drawn special attention to the remarkable resemblance of the Devonian-Carboniferous successions in the Falkland Islands, Argentina, Uruguay, and Southern Brazil to that of the beds in the Cape System, which lithologically and palæontologically possess a striking similarity, many of the species contained therein being identical or very closely allied. The structural parallelism of these areas is also noticeable.

(1) **The Table Mountain Series**^{224 237}.—This series, which owes its name to the well-known mountain mass at the Cape which it forms, has a maximum thickness of 5000 ft. The beds are almost horizontal in the north, but in the west are thrown into folds trending north-and-south, while in the south the folds run east-and-west more or less parallel to the coast line. There is a strong unconformity at the base of the series where it rests on older formations, but no conglomerate. Sandstones or quartzites constitute the bulk of it, accounting for about 4000 ft. The quartzites are usually of a bluish-grey colour, and the passage into them from sandstone is merely the result of the deposition of secondary silica between the quartz grains. Jointing is conspicuous. Pebbles of white quartz are scattered frequently through the rock. Subordinate bands of shales and conglomerates rarely occur. One band of shale or mudstone about 300 ft. thick contains well-striated boulders in its lower part, and this deposit⁹⁸ which occurs in the Cedarbergen is undoubtedly of glacial origin. The boulders consist of quartz, quartzite, sandstone, red jasper, diabase, and granite. In a gritty quartzite on Table Mountain itself

typically scratched pebbles and boulders have also been found. This glacial conglomerate²⁷⁶ has now been found at several other places in the Western Province¹⁹⁷, and one of the most interesting features connected with it is the intra-formational folding²²⁴ in the beds below, which has been probably produced by the passage of the ice-sheet over unconsolidated water-logged sediments¹⁹⁷.

Some indeterminable lamellibranch shells are the only fossils so far found in the whole Table Mountain Series. But from its position and relation to the overlying Bokkeveld Series it is supposed to be either Lower Devonian or even Silurian in age.

In Pondoland^{70 152}, Natal^{64 68 71 239 281}, and Zululand the beds of sandstone are variously coloured, thin and false-bedded; shales are rare. Basement conglomerates are usually present, but no striated boulders have been observed in them⁶⁸. As a rule the beds are horizontal, as in the *Thousand Hills' area²³⁹ of Natal, and have a very extensive outcrop, but are much faulted. There is a great unconformity between the Table Mountain sandstone and the Dwyka Conglomerate of the Karroo System which rests upon it in Natal and Zululand, the upper members of the Cape System being absent and, owing to erosion, the Table Mountain sandstone is sometimes reduced to a few feet in thickness. In southern Natal^{79 281} the beds well exhibit the effects of the earth-movements in pre-Dwyka times, certain faults affecting them, but not shifting the Karroo deposits. It is supposed that all the arenaceous material in this series was derived from regions to the north and was deposited under non-marine conditions.

(2) **The Bokkeveld Series.**—Everywhere in the Cape Province these beds succeed the Table Mountain Series conformably. They have only been found in the folded region south and west of the Karroo. In character they are mainly argillaceous, but there are also thick arenaceous bands occurring regularly over wide areas. The series has the shales and sandstones arranged in definite order, and five principal groups of the former have been distinguished. The total thickness of the series is about 2500 ft.

No outliers have been found in the pre-Cape region to the west and north, and they are quite absent from Natal.

A rich Devonian fauna^{5 141} has been collected from these beds, the affinities of which are with the equivalent beds in the Falkland Isles and South America^{8 277}, many of the species being identical. It indicates a Lower Devonian age, and comprises many trilobites, brachiopods, lamellibranchs, etc., amongst which maybe mentioned *Homalonotus herscheli* Murch., *Phacops (Anchiopella) africanus* Salt., *Leptocælia flabellites* Conr., *Spirifer orbignyi* Morr. and Sharpe, *Chonetes fallkharidicus* Morr. and Sharpe, *Ambocælia umbonata* Conr., *Vitulina pustulosa* Hall, *Nuculites abbreviatus* Sharpe, *Palæoneilo antiqua* Sharpe, *Bellerophon quadrilobatus* Salt., *Tentaculites crotalinus* Sharpe, *Conularia africana* Sharpe, etc. Specially abundant are species belonging to the genus *Homalonotus*, and to certain peculiar subgenera of *Phacops*²⁵⁴, while members of *Spirifer*, *Nuculites*, and *Palæoneilo* are numerous⁵. The peculiar composition of this fauna of the southern Devonian seas and the distinctive features which mark it off from that of more northern regions have suggested the idea that it was separated by a continental barrier of land, which Schwarz²⁵ has called 'Flabellites Land' from the abundance of the brachiopod *Leptocælia flabellites* in this southern fauna. The existence of a southern zoo-geographical province in Lower Devonian times has been suggested²⁸⁰ in explanation of the marked difference in the character and composition of the faunas, but this has been questioned^{254 278}. The palæontological resemblance of the fauna of the Bokkeveld beds with that of the Falkland Isles (*q.v.*) is, however,

a remarkable feature, as Clarke⁶ noticed, and the present author emphasised. Allan²⁶⁴, in discussing the question in connection with the Devonian of New Zealand, considers the latter to have rather European affinities.

(3) **The Witteberg Series.**—The Bokkeveld beds pass up gradually into this overlying series which consists of white quartzitic sandstones and shales, having in all a maximum thickness of about 2500 ft. The peculiar and problematical *Spirophyton* is the most abundant fossil, if it is of organic origin. But a few poor plant-remains have also been found which suggest an Upper Devonian or Lower Carboniferous age. Amongst them such genera as *Lepidodendron*, *Sigillaria*, and *Cyclostigma* have been identified^{31 31a 300 301}. The beds, which form several important ranges of mountains on the south side of the Karroo, first appear in the west, north of Eland's Vlei on the east side of the Cedarbergen, and undoubtedly once extended over the whole southern and western portion of the Cape Province. In common with the other members of the Cape System they are involved in the folds of the marginal zone.

2. Northern Geological Province

In this northern geological province the succession of pre-Karoo beds is most complete in the Transvaal, where it has been minutely investigated in connection with mining enterprises and forms the standard of comparison with adjacent regions. Its classification and nomenclature here established are capable of wide application in South Africa^{135 153 159 163 177 188 189 215 226}
236 246 279 285 306

These pre-Karoo rocks of the Transvaal and Natal are arranged in the following five systems (in descending order) :—

5. Waterberg System.
4. Transvaal or Potchefstroom System.
3. Ventersdorp System.
2. Witwatersrand System.
1. Swaziland System (including the Pongola System ?).

If we do not adopt the view that the Waterberg System is the stratigraphical equivalent of the Table Mountain Series (as is maintained by some geologists), there is no representative of the Cape System in this northern province, and all the above five systems belong to the pre-Cape group of the southern province. In the case of southern Natal the occurrence of the true Table Mountain Series, which has been above described, seems unquestionable.

But since the outcrop of the underlying older crystalline and metamorphic rocks of Natal is separated by a considerable gap from those in the Cape Province, whereas it is in direct continuation with those of Swaziland and the Transvaal, it is convenient to describe the old pre-Cape rocks of Natal with those of the northern province.

(1) **Swaziland (and Pongola ?) Systems.**—The rocks belonging to these systems in the Transvaal belong to the Fundamental Complex and are separated by a marked unconformity from the overlying Witwatersrand beds, and in Natal from the Table Mountain Series, where they have been termed the 'Metamorphic Series'^{64 68 77}. They comprise the oldest rocks in this part of South Africa, and include a group of conglomerates, quartzites, red shales, banded ironstones, slates of many types, phyllites, crystalline limestones, etc.⁷⁹, which are for the most part intensely disturbed. This sedimentary facies of the Swaziland System is sometimes known as *Moodies Series*^{74,118}, and is widely spread in the eastern Transvaal. In Natal the

so* called 'Marble beds' are limestones belonging to it which have been intruded and much altered by alkali-granites and metamorphosed by dynamic processes. In southern Natal²⁸¹, along the coast north of Durban, the *Tugela Series* of hornblende-schists represents part of the Swaziland System.

The so-called *Pongola System*^{77 187} in northern Natal around Vryheid²⁵², which rests with a great unconformity on the basement gneisses and some granites, may probably be equivalent to the Moodies Series in part. It reaches a thickness of 35,000 ft. and is composed of a lower group chiefly of lavas and an upper group of sedimentary beds (quartzites and shales), all of which are unfossiliferous. The lower group may be equivalent to the *Jamestown Series* of Barberton of altered igneous rocks and to the *Tugela Series* of southern Natal. But, according to other views, the Pongola System represents part of the Witwatersrand and Ventersdorp Systems of the Transvaal (see below), and this view appears to be more correct.

There are also included in this System basic schists⁷⁵, hornblende-, mica-, chlorite-, and talc-schists passing into massive serpentines (*Jamestown Series* and *Onverwacht Series* of the Barberton district¹¹⁸), but apparently older than the Moodies Series. The *Onverwacht Series* of the eastern Transvaal consists largely of amygdaloidal lavas, quartz porphyries, tuffs, carbonate rocks, cherts, and schists. The correlation of these series²⁴⁷ with those in the Cape Province is uncertain, but all are included in the Basement Complex. The amphibolitic and allied types of schists are conspicuous members of the Swaziland System, and talc- and chlorite-schists are common, as are also dolomites and serpentines, partly intrusive. All these rocks are invaded by masses of granite⁷⁵, gneiss and allied rocks⁴³; finally there have been later intrusions of other igneous rocks (chiefly basic), piercing both the granites and metamorphic series. Rocks with precisely similar characters are found in the Rhodesian Plateau. (See 'Rhodesia'.)

There are several interesting analogies between the rocks of the Barberton district and those of the Lake Superior region in Canada; the Jamestown Series resembles the Lower Keweenaw, the Moodies Series recalls the Upper Huronian, and the so-called 'older granite' of Barberton may be paralleled with the Laurentian (see chapter on 'Canada').

In the Transvaal the Swaziland System is largely exposed in the north and east⁴⁸ (Pietersburg, Murchison, and Barberton¹¹⁸ districts) as above mentioned, and comprises a great variety of rocks of igneous or sedimentary origin, mostly highly metamorphosed. In many localities the peculiar magnetite-quartz-slate or 'calico-rock' attains a considerable thickness. This rock consists of alternating thin bands of white granular quartzite and black or brown bands of magnetite (with some haematite and limonite) and red bands of jasper; these bands are sometimes straight, but sometimes bent or folded or faulted. The precise mode of origin of this rock is a matter of dispute. (See 'Rhodesia'.)

In the Mafeking and Vryburg district the so-called *Kraaipan Formation*^{90 102}, which consists of banded magnetite quartzites, cherts, jaspers, schists, and some igneous rocks, belongs to the Swaziland System. The beds are all intensely folded, and are not less than 10,000 ft. thick. The series extends into Bechuanaland and the Kalahari. The most conspicuous rocks in it are the black-, brown-, or red-banded ironstones which are magnetite-haematite quartz-schists, and the massive red jaspers. The volcanic members, consisting of diabase-lavas and, in places, of tuffs and breccias, are interbedded. The adjacent granite may be intrusive, but the series is overlaid by the Ventersdorp System, the conglomerates of which contain boulders of the underlying rocks.

The granites which cover wide areas in this northern South African province are either normal, banded, or gneissose. Evidence of contact-alteration in

the surrounding rocks is general, as in the Barberton district, where both the Moodies and Jamestown Series have been invaded and metamorphosed in Natal a high degree of metamorphism has been produced.

The later group of intrusions above mentioned consists largely of epidiorites, sometimes crushed into hornblende-schists, but include also serpentines and various other igneous rocks.

It is not the case that all the granites and other intrusive rocks associated with the Swaziland System are of the same age. In the Murchison Range certain granites (called the 'older granites') pierce the schistose complex, but the 'Palabora plutonic complex,' which includes granites, syenites, pyroxenites, and intermediate types as well as dyke-rocks, is regarded as younger than the 'older granites,' but probably of earlier date than the Transvaal System⁴³. In the southern Transvaal there are three main masses of intrusive granite⁴¹, one between the Witwatersrand and Pretoria⁷⁵, another east of Heidelberg, and another near Vredefort⁶⁵¹, but the last is probably of later age and intrusive into the Witwatersrand beds. Two distinct intrusions of granite have been recognised in south Swaziland, one of which is pre-Pongola in age, while the other, a red granite, is post-Pongola²⁹².

The masses of granite which occupy large areas in the southern and eastern Transvaal^{46 118 159 302}, and cover most of Swaziland, vary somewhat in structure and composition, and frequently pass into gneisses owing to subsequent movements. Marginal modifications in composition are frequent⁷⁵; where they intrude the older schists, etc., phenomena of contact-alteration are often well developed¹¹⁸, and it is along the contact belt that most of the mineral deposits are situated. For the Swaziland System (see *Economic Geology*) is the home of many minerals of economic importance, particularly gold, tin, and copper, and their occurrence is intimately connected with the igneous intrusions.

(2) **The Witwatersrand System**^{212-17 110 113 125 153 177 182 188 189 198 205 210 215 234 240 246 271 279 305 306 323 336}.—This system, which is typically developed in the southern Transvaal and adjacent parts of the Orange Free State, is clearly separated by unconformities from the Swaziland System below, and from the Ventersdorp System above; where the base is seen it rests on the eroded schists and intrusives of the older system. It forms a wide belt north of the Vaal River from Klerksdorp on the west to Heidelberg on the east, but much of the great syncline to the south, into which the beds are thrown, is hidden below later formations. The development of the Witwatersrand System outside the Rand has been summarised by Nel in a recent Presidential Address²⁷⁹.

The rocks belonging to the Witwatersrand System are characterised by their highly siliceous nature. They consist of conglomerates, grits, quartzites, and slates, the succession varying in different places. In the Witwatersrand, where they have been most closely studied, their thickness amounts to 20,000-24,000 ft., the maximum being attained in the Central Rand. No fossils have been found in them, but gold is widely distributed. The System is divided into an Upper and Lower Division on arbitrary grounds at the horizon of the 'Main Reef,' but the whole series is continuous and conformable. The lower division is chiefly composed of slates with only some subordinate (though prominent) beds of quartzite, and a few of conglomerate, while the upper division consists of a succession of quartzites, grits, and conglomerates with only one conspicuous band of slates. The groups of conglomerate beds are called 'reefs' in mining phraseology, and the so-called 'slates' are merely fine-grained siliceous or argillaceous rocks with or without slaty cleavage. Interbedded with the slates and quartzites are sheets of diabase of the nature

of lava-flows which often extend for great distances on the same horizon (*e.g.* Bird Reef Amygdaloid in the East Rand^{113 125}).

On the Rand, where the development differs¹⁸² somewhat in the western, central, and eastern parts, the System is exposed in the axial portion of a great anticline running approximately east-and-west, and followed on the south by a syncline which causes the beds to crop out in the Heidelberg district. A great fault, the Rietfontein fault, traverses them from east to west. The beds dip to the south in the principal area at steep angles which decrease with depth. The strike of the beds bends round to the south at the extreme west end⁷⁶ of the Rand, where the important West Rand fault^{16 215} cuts across this strike, and finally these beds disappear beneath younger ones. In the East Rand^{125 246} they also turn to the south, and here they form a shallow synclinal basin¹¹³, covered to a large extent by the younger Dolomite Series and the Karroo beds, which have been much more completely denuded from the Central and Western Rand. In all cases the rocks have been considerably broken by faults⁷⁶ and penetrated by numerous intrusive dykes and sheets of igneous rocks. On the south of the Johannesburg mass of granite the beds in the Central Rand on the whole form a shallow synclinal which has been compared to a broken soup-plate, the southern edge of which is on the south side of the Vaal River. All the beds dip inwards into this shallow basin, which has been much broken up, and the fragments, while retaining to some extent their relative positions, have in some cases sunk, but in other cases been thrust up, tilted, or forced along over adjacent pieces; finally all the cracks have been filled up by molten igneous material, mostly diabase²⁷¹. The above-mentioned Rietfontein fault extends in a curved line from Rietfontein on the east westwards through Johannesburg, by Maraisburg, into the country north of Roodepoort and Krugersdorp^{13 16}; the strata on the south side are inverted or vertical, while those on the north side have low dips.

The conglomerates ('reefs') are the most important rocks because of their frequent auriferous character, the amount of gold varying much according to the horizon¹⁸². Though differing somewhat in minor respects in the successive zones, they consist essentially of rounded fragments of quartz, and to a much less extent of quartzite, set in a matrix of quartz-grains, the whole cemented together into a hard and compact rock by secondarily deposited silica.

The name 'banket,' meaning 'almond-rock,' is universally applied to this type of conglomerate on the Rand, and the beds are generally termed *banket-reefs.' The quartzites and slates likewise owe their characters to a similar deposition of silica between the grains of coarse sand or fine mud.

Many of the sediments of the Witwatersrand System, including some at any rate of the conglomerates, may be regarded as of the nature of fluvialite or deltaic rather than marine beach deposits, and the uniform character, wide extent and thickness of the earlier beds in the System suggest that they represent the discharge from one or more large continental rivers^{110 113 198 210}. The whole question of the origin of the deposit is discussed by Reineck²¹⁰.

The falling off of the development of the conglomerates to the south and south-east of the Witwatersrand area indicates that the source of the material lay to the north-west. The details of the geology of the various mining areas and mines are given in many independent papers^{284 246 279 305 306 336}; the general geology of the country around Johannesburg has been described by Mellor¹⁵³, that around Heidelberg by Hatch¹²⁶ and Rogers¹⁷⁷, that around Klerksdorp by Nel^{188 189} and Beetz³⁰⁴, while others have dealt specially with that of the Central Rand⁸⁰⁵, Far East Rand³⁰⁶, and Far West Rand²¹⁶. The probable occurrence of the Witwatersrand Series in the Orange Free State, though buried deep by later formations, was discussed by Sawyer and Nel²⁷⁹.

(a) *Lower Witwatersrand Division*.—This group of beds is well exposed in the range of low hills forming the northern boundary of the gold-mining region, and presents an abrupt escarpment to the north. In the Central Rand¹³ the beds have a thickness of 10,000-12,000 ft. The maximum thickness is about 15,000 ft.

They are divisible into three series. At the base is the *Hospital Hill Series*, above comes the *Government Reef Series*, and at the top the *Jeppestown Series*. There are no conglomerates in the Lower Witwatersrand Division in the Central Rand, but there are several in the East and West Rand, and the succession also varies in different parts of the area. The Hospital Hill Series consists of quartzites, slates, and arkoses bearing many distinctive names. Amongst these beds the so-called Hospital Hill Slates may be mentioned, because near their base is a characteristic striped band of 'calico-rock' consisting of alternating and contorted layers of red jaspery quartz, white quartz, black specular iron and magnetite; it has been compared with the similarly laminated rock of the Marquette Iron Range of Lake Superior.

The Government Reef Series consists of hard quartzites and beds of coarse grits and pebbles, alternating with thick bands of slaty ferruginous shales. In the Government Reef Series east of the town of Heidelberg there is a glacial deposit consisting of a grit containing striated boulders of various rocks, and near Klerksdorp³⁰⁴ two tillites have been found on horizons at least 600 ft. apart^{163 189 276}.

The Jeppestown Series, which is from 1400 to 3700 ft. thick, is composed of coarse quartzites and ferruginous slates, less resistant to weathering.

The Lower Witwatersrand Division thickens in the Western Rand but, on the other hand, the Upper Division becomes much thinner^{16 76 306}.

Representatives of the Hospital Hill Series have been recognised in the Ulundi district, Zululand⁶⁸, and it is believed by some that the thick series of sedimentary and volcanic rocks in northern Natal⁷⁷, above described as the 'Pongola Series'¹⁸⁷, represents partly the Witwatersrand System and partly the Ventersdorp System, as above mentioned.

(b) *The Upper Witwatersrand Division*^{113 182 305} is the great repository of gold in the Rand district, and has a thickness in the Central Rand of about 7000 ft. (excluding the Elsburg Reefs), according to Hatch². Quartzites predominate, but conglomerates, grits, sandstones and slates are also present. The conglomerates¹⁰ are, economically, the most important, because of their auriferous character. They are confined to definite zones remarkable for their persistence along both their strike and dip. These zones or 'reefs' have received distinctive names, which (in descending order) are as follows, and are separated by quartzites, but the intervening beds vary much in different parts of the area; between (4) and (3) there is a persistent band of slates of variable thickness known as the Kimberley Slates.

4. Kimberley Reef Series.
3. Bird Reef Series.
2. Livingstone Reef Series.
1. Main Reef Series.

Mellor¹¹³ considers that the Kimberley Slates form the only natural division between the series, and he groups all those below these slates under the name 'Main Bird Series'; the most recent^{163 247} classification combines the Main and Bird Series, and above it puts the Kimberley and Elsburg Series together, though in earlier classifications the Elsburg Series was separated and put at the base of the Ventersdorp System instead of at the top of the Witwatersrand. Details of the Elsburg Series are given below in the description of the Ventersdorp. There is a slightly different development of the Upper

Witwatersrand in the Eastern³⁰⁶ and Western²⁷⁹ areas, and a considerable variation in the thickness of the beds.

The *Main Reef Series* has been the most abundant producer of gold, and in it three principal payable bands of conglomerate or 'banket-reefs' are recognised. These are known as the Main Reef, the Main Reef Leader, and the South Reef, and are all present in the Central Rand⁸⁰⁵. In some places as many as six beds of conglomerate are present. The Main Reef averages 4-8 ft. in thickness, but is frequently divided into two or more bands by layers of quartzite. The uniform size of its pebbles is a characteristic feature. The beds seem to form flat lenticular masses dovetailing into one another and varying in thickness. The Main Reef Leader, which is very persistent, averages 2-6 ft. in thickness, and is usually split up by thin quartzite partings. The pebbles³²³ in it vary considerably in size. The South Reef, which shows considerable variation in its degree of development in different places, is characterised especially by a well-defined banded structure, several bands of conglomerate generally alternating with bands of quartzite. In the Far East Rand the Main Reef and South Reef are not believed to be represented 12 125 246 306 and seem to have died out completely¹¹⁰, while the Main Reef Leader which is present tends to be patchy and discontinuous. The latter reef is absent from the West Rand. There is thus in the Eastern Rand, as a rule, only a single principal reef, the Main Reef Leader, often called the Van Ryn Reef, but in the Western Rand there are two reefs. The so-called 'Black-Bar,' or 'Interbedded Dyke,' is a dark, originally argillaceous or very fine siliceous rock, which is associated with the Main Reef and Main Reef Leader, and usually is from 2-3 ft. thick in the Central Rand; it thickens considerably in the Eastern Rand, where it joins with the slates of the Lower Witwatersrand System to form the 'slate foot-wall' of the Main Reef Leader. The variability of the beds below the Main Reef Leader is a matter of much difficulty in tracing the reefs.

The other series of 'reefs' have the same general characteristics, but are of comparatively slight economic importance, though in the Eastern Rand the Livingstone reefs carry fair gold values¹¹³. In the Bird Reef Series there is a vesicular lava-flow 250 ft. thick in the East Rand, but it is absent in the Central Rand. The Kimberley reefs attain their strongest development in the West-Central and West Rand.²¹⁵

The auriferous conglomerates consist almost entirely of rounded pebbles⁸²⁸ of white, bluish, opalescent, or smoky pellucid quartz, embedded in a matrix of quartz-grains and firmly cemented together by secondary silica. The pebbles are apparently derived from the breaking-down of ancient vein-quartz, and vary in size from a pea to a hen's egg or are occasionally larger. In the Main Reef Series they average a walnut in size. Pebbles of a very fine-grained quartzite come next in frequency, and pebbles of quartz-porphry and other rocks are occasionally present. The distribution and position of the pebbles varies. Finely divided iron-pyrites and native gold occurring as scales or in irregular angular particles which are aggregated round the pyrites, are disseminated throughout the matrix in varying quantities; galena, blende, and copper pyrites also are present, but rarely. The silicification of the rock is so complete that a fracture passes indiscriminately across pebbles and matrix. The gold occurs exclusively in the matrix, or has been secondarily introduced into cracks in the pebbles. The average gold-content of the ore treated on the Rand at present is 6½ dwts. per ton. Various other minerals of primary or secondary origin occur in the conglomerate. Amongst those of primary origin are diamonds (of alluvial source), zircon, chromite, and iridosmine, while the secondary minerals include chlorite, sericite, authigenic quartz, and carbon in granules or veinlets.

Metasomatism seems to have played a very important part in the mineralisation of the conglomerates, but there are the following three leading theories^{110 114 205} as to the origin of the gold and pyrites. (1) The placer theory, according to which the conglomerates are regarded as derived from the denudation of older auriferous quartz reefs, the gold having been then dissolved and redeposited; (2) the infiltration theory, according to which the gold and pyrites were brought in by water carrying them in solution subsequent to the formation of the banket; and (3) the precipitation theory, according to which the minerals were chemically precipitated at the same time as the pebble-beds were being formed in the water. The evidence available now seems strongly to point to the detrital origin of the gold¹¹⁰, and the formation of the Rand conglomerates is believed to be closely similar to that of the coastal-plain placers of Nome, Alaska. Another theory, the hydrothermal, has been recently brought forward¹⁹⁸ and has received considerable support. The arguments¹⁶¹ in support of these various theories are given in a discussion on their relative values, by R. B. Young and others²⁰⁵. The placer deposit theory is most favoured, but there must have been solution and re-precipitation of the gold subsequently, though it is probable that much of the detrital gold was in a fine state of division when first deposited. We may perhaps also compare the Tertiary placer deposits in the Cariboo region of British Columbia with these conglomerates.

*Faults*⁷⁶.—Two principal groups of faults are distinguished in the Central and West Rand¹⁶; these originated under very different conditions and at widely separated periods of time. The first group, represented by the above-mentioned Rietfontein fault, which affects both areas, includes also the Witpoortje and Roodepoort faults of the West Rand. Members of this group are the dominant ones, and they were formed during a period of tension subsequent to the effusion of the amygdaloidal diabase of the succeeding Ventersdorp System, but prior to the formation of the Black Reef Series of the Transvaal System. Their trend is mostly between W.N.W. to E.S.E., and W.S.W. to E.N.E. These are mainly strike faults of the overthrust type. The second or later group of faults appears to have been formed under conditions of compression, and makes large angles with the earlier group. Intrusive igneous rocks²⁷¹ play a large part in the succession and working of the auriferous conglomerates and comprise sheets and dykes of dolerite and diabase.

(3) **The Ventersdorp System**^{159 188 189 253 336}.—At the base of the Ventersdorp System, which consists mostly of igneous rocks, is a series of sedimentary beds 3000 ft. thick in the Central Rand, which is known as the *Elsburg Series*, and by some geologists^{110 113 163 247} is now grouped with the Kimberley Reef Series of the Upper division of the Witwatersrand System, though it possesses distinctive characters and in places is said to rest unconformably upon it, or to show overlap on to the Lower division. According to Mellor¹¹³, on the other hand, there is no evidence of unconformity, but only of an overlap. The Elsburg Series consists of quartzites alternating with impermanent lenticular beds of quartzitic conglomerates, sometimes poorly auriferous, which attain their most conspicuous development to the south of the Central Rand¹¹³. The whole thickness of the pebbly deposits is over 1500 ft., and in the coarser bands pebbles of 6 inches in diameter or more are common, but in the eastern and western portions of the Rand the constituent pebbles are smaller¹¹⁰. The great mass of the Ventersdorp System²⁶³ is composed of a thick series of acid and basic lavas, tuffs, breccias, etc., with intrusive quartz-porphyrines. The lavas are chiefly amygdaloidal and porphyritic diabbases with the vesicles filled with quartz, agate, opal, calcite, and chlorite. The flows are often of immense thickness, aggregating at least 5000 ft., and are well displayed in the Klip

River Hills south of Johannesburg Acid lavas are less common. At Ventersdorp fragmental beds are associated with the basic lava-flows, and comprise volcanic breccias and tuffs with boulder and pebble beds, which have frequently become schistose owing to shearing.

The most northerly exposure of this System is in the Marico district and, after a wide outcrop in the S.W. Transvaal, it passes southwards into the Cape Province where, in the neighbourhood of Vryburg⁸⁸ and Mafeking, it forms an interesting succession of rocks which have been termed the *Pniel Series*, the *Kuip Series*, and the *Zoetlief Series*. These three groups are unconformable. The lowest or Zoetlief Series, which at Kimberley rests almost horizontally on the old granite foundation and is 1300 ft. thick, is characterised by quartz-porphyrries (devitrified rhyolites) which are often amygdaloidal; some andesites also occur, and in places sedimentary beds (arkoses, quartzites, etc.) are found at the base of the series. These rocks extend down to the Prieska area⁴⁰. Near Omdraai's Vlei the Kuip Series is present, and consists chiefly of diabase lavas and sedimentary rocks about 1500 ft. thick. The Pniel Series covers a wide area east of the Langebergen in the north of Cape Colony, and comprises chiefly diabase lavas, volcanic breccias, and sedimentary beds (conglomerates, quartzites, etc.) which are interbedded. The Pniel Series extends far into Bechuanaland. Perhaps the volcanic series, known as the *Koras Series*^{78 88}, on the Orange River above Upington, is also referable to the Ventersdorp System, but it may be of much later date; it rests unconformably on the Kheis Series and consists of quartz-porphyrries and amygdaloidal andesites. The volcanic rocks in the Komati River Valley resemble in some penological characters the lavas of this System, but they may be much older and possibly represent only a local series interbedded and contemporaneous with the Swaziland System¹¹⁸.

(4) **The Transvaal or Potchefstroom System.**—This system and its equivalents, which bear various local names, has an immense development in South Africa, extending over wide areas. Previous to its deposition the older rocks had been worn down to a plane, and the basal beds of the system rest upon this eroded surface. It is supposed to be equivalent to the Nama System in the south-east area of the Cape and South-West Africa and to the Lomagundi System in Rhodesia. In the Transvaal itself it reaches a thickness of 18,000 ft., and consists of unfossiliferous sedimentary beds of an arenaceous, argillaceous, or calcareous character. The beds are, as a rule, little disturbed, and dip at low angles. In the Capo Province^{40 90} it is likewise an important series in the north-western districts, and extends into South-West Africa and covers a great part of Bechuanaland. The stratigraphical divisions of the System are named as follows in the two areas (in descending order) :—

<i>Transvaal.</i>		<i>Cape Province.</i>
iii. Pretoria Series	=	Griqua Town Series,
ii. Dolomite Series	=	Campbell Rand Series,
i. Black Reef Series	=	Black Reef Series.

(i) **BLACK REEF SERIES**²⁴⁰.—In the north-eastern Transvaal this series assumes great proportions, and is composed of quartzites, shales, flag-stones, greywackes, and conglomerates, forming a great part of the high escarpment of the Drakensberg^{43 44 202}. In the Lydenburg district it is stated to reach a thickness of over 2500 ft. at Marieps Mountain, but it decreases greatly in thickness southwards and south-westwards, and near Carolina becomes only about 20 ft. thick. It rests unconformably on all the older rocks, but passes up gradually into the overlying Dolomite Series. The chief rocks are dense

quarzites, but at the base there is often a conglomerate with a dark matrix and highly mineralised with sulphides and oxides of iron, which gives the formation its name. The pebbles in it are mainly small and of quartz, but include also some of chert, jasper, and other rocks. Gold is irregularly distributed through it, and near Krugersdorp^{124 240} it is rich in platinum. At Vryburg, in the Cape Province, where the series is 150-300 ft. thick, limestones and some lavas and tuffs are associated with the arenaceous beds.

(ii) THE DOLOMITE SERIES.—In the Transvaal the series of dolomitic limestones and cherts is known as the Dolomite Series, but in Cape Colony the name *Campbell Rand Series* is applied to it. It follows conformably on the Black Reef Series and surrounds most of the Bushveld area in the Transvaal. In the northern Cape Province it extends far into the Kalahari, where it is covered by the sand. The cherts which give it peculiar characters occur in irregular interbedded layers or nodules. The rough surface produced by weathering is very characteristic of the series and, in the Transvaal, where many caves and swallow-holes have been formed in the limestones, the rocks are important water-carriers. In the Cape Province the chief exposure forms the Kaap Plateau, and the beds which are brought up by a low anticline again to the west have a thickness of probably 2000-3000 ft. In the Transvaal the Black Reef and Dolomite series are present in both limbs of the great anticline in the Witwatersrand district, and groups of shales and quartzites are intercalated in the latter series. The northern and southern limbs unite near Krugersdorp and circle round the great Bushveld syncline. On the southern side of the Bushveld there are ferruginous quartzites at the top of the series, and north of the Pilandsberg they grade into banded ironstones which, in places, contain seams of blue asbestos. The rocks extend on the west into Bechuanaland, reappearing in Rhodesia and South-West Africa, while in the north-east of the Transvaal they have an immense development in the Lydenburg district, where the dolomite alone is about 1800 ft. thick and, together with the overlying Pretoria Series, is gold-bearing⁴⁴, the gold occurring in 'cross-reefs' and 'flat-reefs' around Pilgrim's Rest. Many other minerals are also found in the different veins. The thickness of the Dolomite Series is estimated to be 3000 ft. at Elandsfontein and 7500 ft. in the Marico district, but it is generally less and, as in the case of the Black Reef Series, there is a marked reduction from north to south in the eastern Transvaal; east of Carolina it has decreased to 120 ft. Intrusive dykes and sheets of syenite and other rocks traverse it in the Rand and elsewhere, the sheets being remarkably persistent, but as a rule igneous rocks are rare.

In the north-western part of the Cape Province in Griqualand West³⁴⁷ the equivalent *Campbell Hand Series* includes many algal limestones^{243 244 245 296} with structures like *Collenia*. Similar structures are found in the limestones of the Belt Series in Canada and the United States and in Pre-Cambrian beds in Russia. It has been suggested²¹⁸ that the limestones of the Cango Series in Cape Province (above described in the Nama System) should be correlated with the Dolomite Series, but this is uncertain.

(iii) THE PRETORIA SERIES.—There is no unconformity between this Series and the Dolomite Series in the Transvaal, where, in places, it consists of not less than 10,000 ft. of quartzites, flagstones, and shales, with many dykes and sheets of basic igneous rocks which, in the Lydenburg district, increase the thickness to 12,600 ft. There are three main groups of beds, i.e. the Timeball Hill, the Daspoort, and the Magaliesberg, at the top of which there are three contemporaneous volcanic series—the Ongeluk, the Maehadodorp, and the Dullstroom. In the Daspoort Group a thin 'glacial zone' of quartzite with flattened pebbles, sometimes scratched, is remarkable²⁷⁶. The rocks form striking physical features, the hard quartzites (which possess many local

names) weathering out as long ridges, escarpments, or "kranzes," as in the case of the Magaliesberg²³⁶, the Daspoort, and Timeball Ranges. The Pretoria Series crops out as a wide band east of Pretoria, bending round with the change in strike and increasing in width in the Marico district north-west of the Bushveld Syncline. On the east side of the latter it forms a broad belt inside the Dolomite Series in the Lydenburg district⁴⁴, but thins out to a marked extent to the north of Lydenburg. The interbedded iron-ore deposits (*e.g.* in the Rustenburg district) are of importance, and veins of silver, lead, copper, and cobalt exist in several localities. The igneous rocks^{80 81}, which are associated with the Pretoria Series in the Transvaal, seem to be partly intrusive and partly contemporaneous. The former comprise sills of dolerite or diabase, as well as dykes of the same rocks and of syenite; the dykes consist of amygdaloidal andesites and pyroclastic rocks corresponding to the so-called 'Ongeluk Group' in the Cape Province (see below)⁸⁰.

In the northern Cape Province the equivalent of the Pretoria Series is known as the *Griqua Town Series*⁸⁸, and this is divided into a lower, middle, and upper group, but the three groups seem to form a continuous succession, lying conformably on the Campbell Rand beds. The Series is developed in the north-west of the Province, covering much of Griqualand West^{203 347}, and parts of Bechuanaland. The lower division consists typically of banded cherts or jaspers, coloured with iron, with layers of crocidolite¹¹², as seen near Prieska, and subordinate quartzites, grits, limestones, and shales. Locally there has been silicification, and jaspery ironstones are conspicuous in the Series. The beds are often contorted or even brecciated, as in the case of the Blink Klip¹⁴⁹ breccia, owing to the solution of the underlying limestones. There is a peculiar boulder-rock or tillite^{100 276} near the top of the division which is under 100 ft. thick, but is known over an area of some 8000 sq. miles west of the Orange River; it is a bluish-grey rock containing pebbles and boulders of limestone and chert and occasionally of quartzites, which have one or more sides flattened and scratched; the whole deposit seems to be of glacial origin²⁵. The middle division or Ongeluk Group^{40 100} is 1000 ft. thick, and consists chiefly of andesitic lavas, occasionally amygdaloidal, with some brightly coloured jaspers and cherts. The upper division consists of phyllites with some quartzites, limestones, cherts, and jaspers, and is about 2500 ft. thick. The Blink Klip breccia^{34 9} is rich in iron, being in places almost solid haematite. In the Postmasburg area and Gamagara Hills there are important manganese deposits^{157 185 209 217 247 318 350} (see under 'Economic Geology').

(5) **The Rooiberg Series** occurs in the detached area of the Middelburg basin and was previously grouped with the Waterberg System, being regarded as its lower division. But the Waterberg is found to contain boulders of the red granite which is itself intrusive into the Rooiberg Series, so that it is now separated. The Rooiberg Series consists of a lower group of quartzites, a middle group of felsites, and an upper group of red sandstones, purple shales, and some volcanic agglomerates. Into this series the igneous rocks of the Bushveld Complex (see below) were intruded, but the middle group includes some Bushveld granophyres which seem to form an integral part of the felsites of the middle group; the latter may attain a thickness of 8000 ft. The felsites include lavas ranging from rhyolites to andesites, and have breccias, agglomerates, tuffs, shales, and sandstones interbedded with the flows. The Rooiberg Series is seen also in one place to be unconformable to the underlying Pretoria Series.

(6) **The Waterberg System.**—Overlying the Transvaal System, with a great unconformity in the Transvaal, is a series of red, brownish, or purple

sandstones showing much false-bedding and ripple-marking. There is a coarse basal conglomerate and several other beds of conglomerates and breccia at various horizons. The red colour which is frequently conspicuous is due to the presence of many fragments of jasper.

The Waterberg System^{9 127} occupies a vast area in the northern Transvaal, and extends, like the Campbell Rand Series, into Rhodesia and Bechuanaland. In the Middelburg¹⁹ district it has a thickness of 5,000 ft., but probably much more in the Zoutpansberg. There are contemporaneous lava-flows of andesites and basalts, at least 1000 ft. thick, forming the southern foothills of the Zoutpansberg²²⁶.

The extension of the Waterberg System into Southern Rhodesia is called the *Umkondo System*.

In Griqualand West the equivalent of the Waterberg System is known as the *Matsap System*^{2 40 88 100}. It makes a conspicuous range of mountains in the north of Cape Colony, including the Ezel Rand, the Langebergen, and Korannabergen, the beds finally passing northwards under the sands of the Kalahari Desert. They rest with a great unconformity on beds belonging to the Ventersdorp and Transvaal Systems, and attain a thickness of at least 10,000 ft. The beds fall into three divisions, of which the upper and lower are composed of quartzites, sandstones, shales, and conglomerates, and are purplish or reddish in colour. The middle division is chiefly of volcanic rocks, the lavas being andesitic and much altered; but there are also breccias and tuffs and some sedimentary beds.

The whole Matsap System has suffered considerable disturbance in places, and has been much folded in its westward extension. By some geologists it is correlated with the Cape System of the southern part of the Cape Province instead of with the Waterberg.

Intrusive Rocks of pre-Karoo Age.—There are many igneous intrusions in the pre-Karoo rocks of the Cape Province, the precise age of which is at present undetermined. Such are the masses of gabbro and picrite in the Prieska district. But by far the most important and largest mass of eruptive rocks occurs in the Transvaal north of Pretoria, and is known as the *Bushveld Igneous Complex*^{51 80 81}, about which much has been written^{123 127 151 158 159 160 165 169 172 188 189 190 230 241 242 283 298 334 337 346}. This comprises a great variety of rocks, which are all believed to be genetically connected²⁹⁸. The whole complex covers an area of about 15,000 sq. miles, extending for over 250 miles from a point 15 miles west of Marico River to 25 miles west of Lydenburg, with an average width of 60 miles. The igneous material was poured out partly after the formation of the Pretoria Series, the beds of which show contact alteration¹¹⁸, and partly at any rate also after that of the Waterberg System, though before the deposition of any part of the Karroo System. The rocks are often regarded as constituting a huge composite laccolite or batholith, but the eruptions seem to be of various ages and to represent a long period of igneous activity. The history of the igneous activity begins, according to Du Toit¹⁶³, with a volcanic phase seen in the basic lavas and tuffs of the Pretoria Series. A second volcanic phase followed and is represented by the Rooiberg felsites²³⁰. Then followed the first main plutonic phase when a basic magma crystallising as norite was injected into the uppermost part of the Pretoria Series, chiefly between it and the roof of the Rooiberg beds. A phase of injection of diabase sheets then ensued. Then came the second main plutonic phase consisting of the Red Granite 'cutting across and spreading out above the norite.' The last phase was alkalic, as seen in the Pilandsberg^{147 171}, and possibly was subsequent to the Waterberg System (see below). The Norite and the Red Granite are the most important members of the complex. It is thus seen

from the above that the Bush veld Complex consisted of a series of intrusions of many petrological types spread over a considerable period of geological history beginning in the Pretoria Series and not ending till after the Waterberg. One of the most important members of the complex is the 'Red Granite'^{18 58} which occupies a large surface north of the Magaliesberg and in places invades the Waterberg Sandstones¹⁹, but probably more than one intrusion of red granite took place. Coarse pegmatites and red granophyre are found in association with it, the former of which appear to be specially connected with the cassiterite deposits of the Waterberg tin-fields⁴⁵. Associated with the Norite are masses of segregated iron-ore and chromite^{106 337}; the Norite is also the seat of the platinum deposits¹²³. Pyroxenites and peridotites cover a wide area in the Marico district. There seems to be an increasing basicity outwards from the centre to the margins of the complex. Considerable metamorphism in the surrounding rocks²⁰ has been produced by these igneous intrusions. The Vredefort area^{159 188 285 298} is considered as displaying¹ an unique manifestation of the magmatic activity of the Bushveld, and there the intrusion of a mass of granite has forced up the beds of the Witwatersrand, Ventersdorp, and Transvaal systems into a dome, the beds being overturned round its margins. In other parts of the Transvaal there are granite masses, norite, etc., which may belong to the same periods of igneous intrusion as the Bushveld. Shand²⁶⁵ has described another igneous complex at Leeuwfontein, in the Pretoria district, where soda-trachytes, white and red syenites, and foyaïtes occur.

A later group^{21 52 147 171} of alkaline igneous rocks has been distinguished in the Pilansberg in the Rustenburg district, where, subsequent to the invasion of the Bushveld laccolite and to the denudation of part of the Waterberg System (apparently in pre-Karoo times), there took place an eruption of nepheline-syenites, alkali-syenites (without nepheline), and foyaïte, with phonolites, trachytes, tuffs, and breccias containing fragments of the Red Granite. Such alkaline rocks have been described by Molengraaff and Hall in the Vredefort district³⁵¹. Other occurrences of alkaline intrusives have been described by Shand in Sokukuniland¹⁸⁴, where nepheline syenites form plugs in the Red Granite, and on the Transpoort line in the Pretoria district²⁵⁰, while breccias of such rocks have been observed elsewhere²⁵¹. An important series¹⁴⁷ of dykes of diorites, monzonites, syenites, etc., having widths varying from 20 to 250 ft., and petrologically related to the Pilansberg rocks, traverse the Bushveld area and cut all formations and rocks up to the Red Granite. A peculiarity of these dykes is that the central part is frequently more acid than the margins, suggesting that they are composite in origin.

Various ore-deposits, in addition to the magnetite and chromite segregations which have been mentioned above, are common in these igneous rocks, and are represented by lodes or mineralised zones, which contain copper, silver, tin, cobalt, nickel, etc. The occurrences of tin ore are genetically connected with the red granites, and the formation of the ore-deposits in the Pretoria Series is directly related to the intrusion of the Bushveld Complex (see 'Economic Geology,' p. 160).

The Karroo System.—The Karroo System^{128 131 143 144 146 148 150 156 174 187} 195 220 232 235 239 248 303 324 embraces beds ranging in age from Upper Carboniferous to Rhætic, and is wholly of fresh-water or sub-aerial origin, no marine fossils having been discovered in the whole succession, except in South-West Africa (*q.v.*). It is composed of sandstones, shales, and mudstones, with an important and peculiar conglomerate or boulder-bed²⁵ at the base in the south, and a thick series of lavas at the top. A characteristic feature is the abundance of interbedded sheets and of intrusive dykes of basalt and allied igneous rocks throughout the formation^{128 270 271 325}.

The strata are horizontal, or nearly so, over immense areas, and south of the Transvaal lie mainly in a huge shallow basin in the older rocks, covering most of the Cape Province, Basutoland²³², the Orange Free State, and much of Natal, while in the Transvaal they spread out over the south-east portion and again outcrop in Swaziland in a long strip along the west side of the Lebombo Mountains. They are also believed to underlie the recent superficial deposits of a large portion of the southern and western Kalahari Desert²², forming a very flat trough, which probably stretches north into the Bechuanaland Protectorate. Northwards they extend through Rhodesia, Nyasaland and Tanganyika into Kenya and Uganda, as described, but the succession and lithological character of the beds vary in different areas; in the Union of South Africa we have its fullest development. We can distinguish a southern and a northern fades¹⁶³, the dividing line roughly running from Windhoek to Belfast. In the southern area the formation is thickest, and there is an apparently unbroken succession of deposits passing from the Witteberg beds upwards, the Dwyka conglomerate (glacial tillite) forming here the base of the Karroo Series. In the northern area¹⁶³ the whole formation is thinner and the glacial conglomerate at the base is only found in some places and only in the south, while the coal-seams occur on a lower horizon, and there is a stratigraphical gap¹⁷⁴ between the Stormberg Series (Upper Karroo) and the Lower beds. A precise correlation of the beds over the immense area occupied by them is difficult, and local names are employed in the northern parts of their development. The total thickness of the whole Karroo System where most fully represented is over 27,000 ft.

Along the southern margin of their development the Karroo beds have been involved in the later movements producing the folds of the marginal ranges of the Cape Province and Natal¹⁰⁸, and their outcrops are therefore repeated. The origin of the main basin is also due to crustal deformation subsequent to the deposition of the beds.

In the Cape Province their thickness is not less than 20,000 ft., excluding the volcanic beds. But there is a general thinning out of each of the subdivisions of the System (with the exception of the Middle Eccla beds) from the Stormberg region north-east to the Transvaal border. Over the entire Transvaal the thickness is only one-fifth to one-tenth of that in the Cape Province, but this is due in great part to a double overlap and to stratigraphical breaks. It is questionable if the Middle Karroo is present in the Northern Province, though the Upper Karroo is certainly developed there.

The System is now usually divided into four³³⁰³ series as follows :—

Upper or Stormberg Series.
 Middle or Beaufort Series.
 Lower { Eccla Series.
 Dwyka Series.

The two lowest series are sometimes grouped together and termed the Eccla Series, the Dwyka not being separated off².

In the south of the Cape Province the Karroo System succeeds the Cape System conformably, no break being observable between the Witteberg and Dwyka beds. But in every other area the Karroo beds rest on the denuded edges of all the older formations.

Paleontologically, the Lower and Middle Divisions are characterised by containing the widespread *Glossopteris* flora^{57 235}, which is found in India, Australia, South America¹¹⁷, and the Falkland Islands. These facts have widespread implications and concern the whole history of the southern hemisphere (see below), and the geological and paleontological relations between Africa and South America have been discussed, and their close affinity em-

phasised by by Toit^{130 277}, Furon³⁴³, and others. The Upper Division is marked by a basal transgression²⁷⁶ as well as by a distinct flora which, however, makes its earliest appearance in the Upper Beaufort (or Burghersdorp) beds, as described below. The vertebrate remains consist mainly of reptiles belonging to primitive but specialised types⁹⁸, and Seely and others^{4 23 26 101 146 195 220 248 293327} have classified the whole succession of beds by their vertical distribution¹⁵⁸. The flora has been described by many writers^{163 285} and its relations and distribution have been discussed, while the reptiles and amphibia have been described by Von Huene^{146 195 220}, Haughton^{121 143 144}, Broom^{99 342}, Broili²⁹³, Boonstra³²⁷, and others, and the fishes by Brough³³⁰.

Economically, the Karroo System is of great importance, for in it there occur on more than one horizon the only coal-seams¹⁶⁶ in South Africa.

The whole problem¹⁶³ of the nature, history, and extent of a former land connection of South Africa with India, Australia, and South America is still controversial²⁴⁹, but the fact that the flora and fauna²²⁰ of the Karroo beds of South Africa are widely spread over these southern areas is undisputed, and it is chiefly on this biogeographical evidence²²⁰ that the theory of the previous existence of a great Austral Continent, called Gondwanaland^{163 303 309}, depends. The lithological and physical similarity of the beds in these various regions is another important fact³²⁴. A summary of the evidence for the former connection of South Africa with South America²⁷⁷ has been given by Gerth³¹²; the question concerns the history and age of the South Atlantic Ocean as well as of the theory of Atlantis⁸¹⁶. The theory of drifting land-masses has been specially supported by Du Toit³⁰⁷, in the case of South Africa, and it explains many of the resemblances, both physical and paleontological, between the southern continents.

(1) The Dwyka Series.—This series^{131 150}, where it is most fully developed, consists of an Upper and Lower group of shales, but is especially characterised by the occurrence of boulder-beds or conglomerates of much interest, forming a Middle group between them. In the Cape Province it measures 2300 ft. thick. In Pondoland¹⁵² it is only 1000 ft. thick. Throughout the whole of the southern area it is found at the base of the System, but it varies in its development and to some extent in its character. It is present throughout the Cape Province⁸⁷, Natal^{68 219}, Zululand, the southern Transvaal^{27 42}, and Bechuanaland²², extends into South-West Africa⁶⁹, and is represented in Rhodesia. (See below.)

In the southern part of the Cape Province the Lower Dwyka Shales intervene between the quartzites of the Witteberg Series and the boulder-beds, and are undoubtedly of the nature of passage-beds. They vary from about 400 to 1400 ft. thick, and form a conformable transition series.

In the north-western part of the Cape Province (*i.e.* north of lat. 33°), and in the south of the Transvaal and near Durban, the boulder-bed or 'tillite' rests directly on a worn and denuded platform of older rocks; this platform occasionally shows a grooved, polished, or striated surface, and *roches moutonnees* of an undeniably glacial origin^{25 115}, as at Riverton, at Nooitgedacht, and near Kimberley³¹⁹.

The character of the boulder-beds themselves bears out completely the view that we have here a deposit formed by ice and of the nature of a boulder-clay. The tillite¹⁵⁰ is usually a hard bluish rock of the nature of a ground-moraine, with the boulders scattered irregularly through it and rarely arranged in layers. In some places, as in the Vaal-Harts Valley between Douglas and Vryburg, the deposit is largely of shale and seems to have been a glacial mud with the boulders in it dropped by floating ice; in Zululand⁵⁸ it may pass into sandstone containing irregular bands of pebbles. The southern Dwyka

deposits are thicker and more uniform in character than those in the north, and are believed to represent the silt and boulders carried by floating ice and laid down in water in front of the ice-sheet which covered the interior region¹³¹. The northern type is extremely variable, being in some cases of the nature of an unstratified moraine, and in others resembling a sub-glacial till, but in still other cases suggesting rather fluvio-glacial or lacustrine formations in quiet shallow water. In the Dwyka of Middelburg there are typical varved shales, indicating their fluvio-glacial origin. The thickness of the Dwyka Series diminishes northwards, and from the direction of the striae on the glaciated rock-pavements¹³¹ and probable sources of derivation of the contained boulders, the movement of the ice in western Cape Colony is believed to have been from the north-east to the south-west. But in Natal^{70 71} and the central and eastern Transvaal the ice seems to have flowed from the north to the south or to the south-south-east. There seem to have been thus several more or less distinct centres from which the ice radiated^{131 163}, and it is believed that the Dwyka ice formed the southern part of a great ice-cap extending north-west into Angola and over the Eastern Congo to cross the equator, where the movement was mainly northwards into a lake²⁵². According to Du Toit¹³¹ the four centres from which the ice spread southwards were situated in South-West Africa, Griqualand West, the Central Transvaal, and an area east of Natal.

The boulders are of many kinds of rock, partly far-travelled and partly local, and comprise quartzite, gneiss, granite, porphyrite, dolomite, jasper-rock, vein-quartz, etc. In shape, they are mostly sub-angular or angular and less often rounded; many show striations in one or more directions and faceted surfaces typical of ice-action. In size they vary from small pebbles up to huge blocks as much as 10 ft. in length and a ton or more in weight. The boulders are embedded in a hard, dark, compact matrix of fine mud, chiefly composed of quartz and microcline^{131 150}. In the northern district, as near Prieska, bedding is generally quite absent, the boulders being confusedly massed together without any arrangement according to size, and they are of distinctly local origin, so that the contents of the bed vary from place to place. The same features prevail in the south-east Transvaal, and the bed may here attain a thickness of 200 ft. where it was deposited in original depressions, but it averages about 50 ft., and is sometimes altogether absent. The features of the pre-glacial surface can be occasionally distinguished, and some of the existing valleys may indeed be of pre-Karoo age. The whitish shales and mudstones which occasionally occur in the conglomerate represent pockets of glacial mud.

In the southern area there has been, on the other hand, a certain amount of sorting in the constituents of the bed, and intercalated bands of shale and sandstone suggest deposition under water. This type occurs in Zululand⁶⁸ and Natal⁷⁷.

In the Kalahari Desert²² the Dwyka Series seems to have had a special development, for there is evidence of accumulation under marine conditions.

The Dwyka beds have only yielded a few fossils, chiefly in the White Band and Upper Shales, e.g. the small reptile *Mesosaurus* (which also occurs in the Permo-Carboniferous of Brazil), and some plants (*Lepidodendron*, *Gangamopteris*, and *Phyllothea*). But in the adjoining parts of South West Africa⁶⁹ the occurrence of large lamellibranchs, belonging to the genus *Eurydesma*, indicate that some of the glacial material was deposited in the sea. In the homotaxial beds in Australia and Kashmir, where the same genus and species are known, associated with other marine organisms, there is evidence that similar marine conditions prevailed.

In general characters, stratigraphical relations, and position, this Dwyka

glacial deposit agrees with the Talchir Conglomerate at the base of the Gondwana System in India, the Orleans Conglomerate in Brazil, and the Bacchus Marsh Conglomerates and equivalents in Australia. The widespread occurrence of such a set of beds at the base of the formation holding the *Glossopteris flora*²³⁶ throughout the southern hemisphere is the evidence for the existence of a Permo-Carboniferous or Upper Carboniferous ice age^{25 57 117 131}.

The cosmopolitan northern Upper Carboniferous flora appears to have been driven away or exterminated by the advent of this regional refrigeration, and its place taken by the *Glossopteris flora* adapted to the new climatic conditions. In South Africa the older types do not appear to have returned on the amelioration of the climate, as they did to some extent in South America.

At the top of the Dwyka tillite in the Cape Province there is a group of olive-green shales passing up into a band of carbonaceous shales which weather white, forming the so-called 'Whito Band'; this group extends from near Kimberley to Grahamstown, and also spreads into South-West Africa, but in Natal and in the south-east Transvaal there is a stratigraphical break, and these Upper Dwyka shales are missing. Near the base the shales (the Upper Shales) occasionally contain phosphatic nodules, and the carbonaceous shales of the 'White Band' yield some oil, but not of high grade. Layers of chert or cherty concretions are also present near or at the top of the group.

In Bechuanaland near Palapye²⁵ the Dwyka tillite is also found, and in bore-holes elsewhere it is associated with varved or laminated shales which are correlated with the Lower Eccla.

(2) **The Eccla Series.**¹⁰⁸—These beds rest conformably on the Upper Dwyka shales in the Cape Province³, and in the south and west of this Province⁸⁷ they consist of a lower portion, 1000-1200 ft. thick, chiefly composed of shales, and an upper portion, about 1200 ft. thick, chiefly of sandstone. To the south of Aberdeen, the arenaceous phase reaches a thickness of 5000 ft., and more than that thickness at Grahamstown¹⁸³. The shales are usually bluish and dark coloured, or sometimes carbonaceous, but towards Karroo Poort become greenish and purplish, and are associated with some sandstones. The sandstone beds in the Cape Province show a characteristic and peculiar spheroidal mode of weathering.

In Natal^{108 219} a three-fold division of the Eccla Series is generally recognisable, and this division is also recognised in Rhodesia, as previously described, but from the Upper Pongola northwards the lower shales thin out, and the middle arenaceous division comes to rest directly on the Dwyka tillite.

In Natal^{64 67 68 77}, the Transvaal²³⁸, and Orange Free State, this series is of great economic importance, for it contains valuable coal seams¹⁵⁶. The seams vary much in number, thickness, and quality, but some are over 20 ft. thick. In the Witbank⁴⁸ area of the Transvaal, the coal-bearing series averages only 200 ft. in thickness, but in Natal the thickness of this middle arenaceous and carbonaceous division is much greater. Intrusive sheets of dolerite have in places caused much alteration in the coal. The chief coal-mining centres in the Transvaal are near Vereeniging¹⁰⁸, at Brakpan and Springs²³⁸ on the East Rand, in the Ermelo and Carolina districts, and in Natal at Newcastle and Dundee. Mellor^{47 48} would refer the Transvaal coal measures to the Beaufort Series, and it is possible that some of the Natal coal measures may be of Lower, Middle, or even Upper Karroo age⁶⁷, but the majority are referable to the Eccla Series. No true 'underclays' have been discovered, but the casts of stumps of trees and prostrate trunks on the upper surface of the coal have been found in the bed of the Vaal River near Vereeniging. Oil-shales (torbanites) are closely associated with the coal-seams in the Ermelo³¹⁴ and Wakkerstroom²²⁷ districts.

Plant-remains from these beds include species of *Glossopteris* (*G. browniana*, *G. angustifolia*), *Gangamopteris* (*G. cyclopteroidea*—*obovata*), *Noeggeraihiopsis hislopi*, *Bothriodendron*, *Schizoneura*, *Phyllothea*, *Sigillaria brardi*, *Lepidodendron*, etc. Several species are identical with those occurring in the Lower Gondwana beds of the Indian Peninsula. The presence of *Sigillaria*, *Lepidodendron*, and *Bothriodendron* has not been observed in the overlying Lower Beaufort beds. The Upper Eccla shales contain fish-scales (*Acrolepis*)³³⁰ and the plant *Dadoxylon*. Of lamellibranchs, the genus *Palæomutela* has been recorded, and some reptilian remains have also been found.

Eruptive rocks occur with comparative rarity in the Eccla Series in the Cape Province, but some are found near Kimberley. On the other hand, intrusive sheets and dykes are a specially striking feature in the Middle Eccla beds in northern Natal^{77 108 270}.

The Upper Eccla shales are remarkably uniform in character and thickness in Natal, ranging from 500 to 700 ft., and contain concretionary nodules and layers rich in phosphate of lime.

(3) **The Beaufort Series.**—In the Capo Province⁸⁷ this series has been palaeontologically divided into the *Pareiasaurus* beds at the base, succeeded by the *Dicynodon* beds, and these by the *Burghersdorp* beds or zone of specialised theriodonts, the two lower divisions taking their names from characteristic genera of reptiles^{148 146 195 220 310}. Broom and Watson^{26 121} have recognised six zonal divisions marked by reptilian genera. Stratigraphically a three-fold division has been established in the whole series¹⁰⁸. Sandstones, mudstones, and shales are the prevailing rocks, but concretionary and nodular limestones are occasionally found. Many local unconformities occur in the series. The beds succeed the Eccla shales conformably, but are practically horizontal in the Cape Province, and not involved in the marginal folding like the Eccla and Dwyka Series.

The Beaufort Series occupies almost the whole interior of the Cape Province, and spreads over the adjoining and western parts of the Orange Free State; it also covers the slopes of the Drakensberg⁷⁹ in Pondoland⁷⁰ and Natal, and extends over a considerable area to the east. In the Transvaal its presence has not been definitely proved.

In the north-eastern part of the Cape Province the beds reach a thickness of 2000-2500 ft., but in Pondoland they are stated to be as much as 8000 ft. thick²⁶.

The sandstones are usually massive, and form continuous escarpments or flat-topped hills, but sometimes are soft and flaggy; they do not weather into spheroids like those of the Eccla Series, but break off in vertical faces. Their æolian origin is frequently indicated.

The mudstones are unstratified, and show colour-banding. The shales are usually dark blue or green, but the upper part of the series is characterised by red and purple shales. 'Clay-pellet' conglomerates, consisting of a sandstone or mudstone matrix which contains numerous rounded or flattened lumps of mud, are often seen at the base of the sandstone beds. Concretionary or lenticular limestones weathering out as nodules are abundant. Thin layers of coal of no value (unless the Komati Poort beds are of this age) occasionally occur in Natal and elsewhere. Intercalated sheets and dykes of igneous rock⁸⁷ are extremely numerous, and consist of diabase and olivine-diabase, mostly ophitic, and often with columnar jointing.

In Natal the fine yellowish felspathic sandstones and brightly coloured layers of mudstones and shales of the Lower Beaufort beds of the Cape Province become whiter and coarser, and the whole division is reduced in thickness. The middle division is thin, and is marked by a massive sandstone.

The most interesting fossils are the reptiles^{146 195 220 310}, and on the strength of the distribution of the genera the whole Beaufort Series has been divided into three groups and six zones^{56 121}, as above stated, the lowest of which is characterised by *Pareiasaurus*, and the uppermost by *Cynognathus*. The Middle Beaufort beds are marked by the predominance of *Lystrosaurus* and the fish *Atherstonia*. Of other remarkable reptilian genera *Dicynodon* and *Oudenodon* should be mentioned. The lamellibranch genus *Palæomutela* is represented by several species⁸⁷, and the flora comprises many species of *Glossopteris* (*G. browniana*, *angustifolia*, *communis*, *indica*, etc.), and *Schizoneura* in the Middle and Lower beds.

The Upper Beaufort or 'Burghersdorp Beds,' which reach a thickness of 2000 ft. in southern Natal⁷⁹, but thin to the north-east, have a different fauna and flora as well as a distinct lithological development. The sandstones are yellowish or pale blue in colour, and are separated by brilliant red and purple shales and mudstones, etc. In these beds we get the dicynodont *Kannemeyeria*, the labyrinthodont *Cyclotosaurus*, and a number of cynodont reptiles, including *Cynognathus*, *Procophon*, *Galesaurus*, and *Bauria*. The earliest South African mammal, *Karroomys*, occurs on this horizon, and species of the fish *Ceratodus*, *Helichthys*, *Cleithrolepis*, etc., are common. The plants^{57 235} include *Odontopteris*, *T'hinnfeldia*, and *Tceniopteris*, but *Glossopteris* and *Schizoneura* are also still present.

The Beaufort beds seem to be flood-plain or river-channel deposits modified by wind-action, for the vast majority of the reptiles are dry-land types, and mollusca and fish are very rare. It has been suggested that the beds are of the nature of loess, and are connected with glacial conditions and a cold climate²⁶.

With regard to the correlation of the beds, the lower and middle parts of the series indicate the Permian, and the upper the Trias. It is to this Beaufort Series that Kynaston would partly ascribe the coal-bearing series of Komati Poort and of northern Zululand, but probably some of the beds in this district are of Upper Karroo age.

(4) Upper Karroo or Stormberg Series^{144 146 174}.—The Burghersdorp Beds indicate the advent of the Upper Karroo fauna and flora, but in them the older types have not yet entirely died out. In the Upper Karroo beds the *Glossopteris* flora has quite disappeared, and there is present a new flora which is of Rhætic type in the lowest or Molteno Beds.

In the Cape Province^{87 92 144} the Stormberg Series, which is the only one of the Karroo System including coarse-grained sediments, is divided up into the following groups in descending order, and the strata lie almost horizontal or only inclined at low angles :—

- (d) Drakensberg or Volcanic Beds,
- (c) Cave Sandstone.
- (b) Red Beds,
- (a) Molteno Beds.

The Stormberg Series¹⁴⁴ is also developed in the eastern part of the Orange Free State, in southern⁷⁹ and western Natal⁶⁸. In the Cape, Natal, and Basutoland²³² it succeeds the Beaufort beds conformably, but in many parts of the Union it is transgressive¹⁷⁴ over them. In thickness it reaches nearly 10,000 ft., but the volcanic beds constitute nearly half of it. In Basutoland^{25 232} the Upper Karroo formations occupy most of the surface, and possess the same characters as in the adjacent regions, but the volcanic beds have here a maximum development (see below). The Upper Beaufort beds crop out only in the western lowlands. The Stormberg Series extends

also into the eastern and central Transvaal (Komati Poort and Springbok Flats), reaching to the Limpopo and into Rhodesia (q.v.). But the various subdivisions are not recognisable in all these areas, and north of Witzies Holk, below Mont aux Sources, and in eastern Zululand and farther north the Molteno Beds are absent, so that the Red Beds rest directly on the Upper Beaufort beds.

(a) *Molteno Beds*.—This division has a maximum thickness of 2000 ft. between Glen Grey and Elliot, but thins out in northern Natal, as above stated. It is the coal-bearing formation of the Cape Province^{92 96}, and there are some coal-seams also in Natal¹⁹¹ in this division. The beds consist of coarse felspathic sandstones of loose texture, weathering into spherical nodules, and sometimes containing scattered quartzitic pebbles; there are also massive grits, grey or blue shales, and thin or lenticular coal seams, the structure of which suggests drift-origin, and occasionally there are conglomerates. The coal is generally of inferior quality and mixed with shale, while the seams vary enormously in thickness, having often suffered from contemporary erosion. The most important coal-producing area is that of Indwe^{96 156}. The coal, which occurs on three horizons, was accumulated in detached areas.

The plant-remains^{235 297} comprise *Thinnfeldia odontopteroides* Morr., *Teniopteris carruthersi* Ten.-Woods, *Cladophlebis roesserti* Presl., *Stenopteris elongata* Carr, several species of *Baiera*, etc. Many of the same species occur in the Upper Gondwana beds of India, and in the corresponding beds of Australia and South America. The beds are correlated with the Upper Trias or Rhætic.

(b) *The Red Beds*.—The Red Beds succeed the Molteno Beds conformably in the Cape Province, and are of varying thickness up to a maximum of 1600 ft. They are more argillaceous in character, and consist of red, yellow, or white sandstones, and red or purple shales and mudstones with some nodular calcareous rocks. Conglomerates are rare. Reptilian remains¹²¹ and footprints include several genera of dinosaurs (*Massospondylus*), a crocodile (*Notochampsia*), the fish *Ceratodus*, and a mammal (*Tritylodon*). The rich flora of the Molteno Beds is not represented, but silicified wood is rather plentiful.

The Red Beds extend into Basutoland^{26 232} and Griqualand East¹⁸⁶, but decrease in thickness considerably in northern Natal and in the north-eastern corner of the Orange Free State. Red clays (*Bushveld Marls*) 300-400 ft. thick, chiefly represent them in the central and northern Transvaal.

(c) *The Cave Sandstone*.—This is the most conspicuous of the Stormberg sedimentary beds, and consists chiefly of extremely massive white or cream-coloured fine-grained sandstone weathering out into caves at the base of the escarpments or into fantastic pillars and masses. Piebably it is of æolian origin. It is often only 100 ft. thick, but reaches 500-800 ft. in the Drakensberg²⁴, and exhibits great lateral variation. It caps many of the plateaus of the Stormberg district and eastern parts of the Orange Free State. Fossils are rare, but footprints of dinosaurs are occasionally found²⁶, as well as remains of the dinosaur *Thecodontosaurus* and the crocodile *Notochampsia*, while the shales have yielded *Estheria*, insect wings, etc. Volcanic activity began during the deposition of the Cave Sandstone in parts of eastern Cape Colony and Natal^{24 82 92}, lavas and ash beds being interstratified with the upper deposits.

In the Transvaal it is represented by the *Bushveld Sandstone Series*², which has a thickness of 200 to 500 ft., and succeeds the Bushveld marls and Ecca coal-bearing beds near Pienaars River, north of Pretoria and near Warmbaths, in the Springbok Flats, and in the Komati Poort coal-field. The Bushveld

Sandstone Series is represented in Rhodesia by part or all of the so-called 'Forest Sandstones' (q.v.).

The vast area which the Cave Sandstone and its equivalents must have covered, and its internal and uniform characters, have led to the view that it is in the main a deposit comparable to the Pleistocene loess.

(d) *The Drakensberg or Volcanic Beds*.—The greatest development of these beds is in Natal and Basutoland, especially in the Drakensberg^{24 82 92 97 148 232 295 348} and Maluti range, where they are composed of a great series of lava-flows, with rare beds of ash and agglomerate, in all having a thickness of 4500 ft. Some seventy-two vents and diatremes²⁵⁵ have been detected, mostly in the Cave Sandstone, and they were covered up by later lavas (basalts, olivine basalts, with a few andesites and oceanites). Faulting appears to have accompanied as well as followed this episode of volcanicity. In the Stormberg and north-eastern parts of the Cape Province the Drakensberg Beds are likewise important. In the Transvaal the amygdaloidal rocks of the Springbok Flats probably are of the same age, and in Rhodesia their principal development is to be found in the Zambesi Valley (see 'Rhodesia'), while in Bechuanaland (west of Palapye) they are also widely developed. The Bushveld Sandstone is here also present, and the Red marls also occur, capped by the basalts north of Serowe and at the south-east corner of the Makarikari depression⁹⁰. In the South-West Africa Protectorate representatives of the Drakensberg Beds are also present.

The Volcanic Beds in Cape Colony¹⁸⁶ are rarely as much as 3000 ft. thick, but in Basutoland^{148 282} and Natal^{71 187 348} they range from 4000 to 4500 ft. thick and form the Drakensberg³⁴⁸. In some places intercalated beds of sandstone, bedded tuffs, and agglomerates occur, but, for the most part, the series consists only of lava-flows; these are mainly basalts, often amygdaloidal⁶², together with some augite-andesites, etc. The volcanic activity commenced in the Cave Sandstone period, as above mentioned, for lava-flows are intercalated with it in places. The volcanic rocks of the Zuurberg between Sandflats and Enon are now known to be post-Dwyka, but pre-Cretaceous in age.

In Barkly East the interbedded sedimentary rocks and stratified ash-beds indicate that the earlier eruptions took place under water. Most of the lavas seem to have been poured out from fissure-eruptions, but in some cases the vents are represented by plugs of agglomerate²⁴. In Natal⁷¹ and Basutoland it is the lava-flows of this age which compose most of the mountain ranges and plateaus, and here numerous plugs of agglomerate and intercalated ash-beds have been discovered⁵⁹. In the Stormberg area²⁵⁵ a large number of volcanic necks are distributed in a most irregular manner, some of which are filled with doleritic lava, and others with agglomerate. These necks^{24 82} vary much in size; the Belmore volcano in Barkly East is about three-quarters of a mile in diameter, and there is one near Matatiele⁸² still larger. Associated with the necks are numerous dykes and sills, but of somewhat later date, and the whole volcanic series shows evidence of repeated eruptions spread over a considerable period.

The dykes and sheets of this volcanic period (possibly continuing into Cretaceous times) are extraordinarily abundant in the Cape Province^{82 92 101 128}, and penetrate all the older rocks. The commonest are doleritic dykes²⁷⁰, but the dolerites^{270 325} are nearly wholly absent from the southern and western folded belts of the Cape¹⁶³. In Basutoland the dykes are most conspicuous objects, and are traceable for many miles. Some of the sheets, which are often horizontal, extend over enormous areas; the lowest sheet, north of Hopetown, must have been continuous, according to Rogers⁸, over at least 5000 square miles (in the Cape Province) without reckoning the area it

occupied in the adjoining part of the Orange Free State.' The sheets are in some cases 500 to 900 ft. thick, and their surface frequently shows undulation, as in the case of the extensive Glen Grey sheet⁹⁶ in the Cape Province. The metasomatism²²⁶ produced in the rocks which they invade is not, as a rule, intense, but columnar jointing has been occasionally caused, and coal seams have been burnt or changed into anthracite.

In Pondoland^{70 152 212} and East Griqualand^{72 186} there are massive intrusive sheets of gabbro, norite (as at Insizwa)²⁸⁴, or picrite (occasionally with copper and nickel ores) which pierce the Beaufort beds and have metamorphosed them. Similar rocks occur in southern Natal⁷⁹, and the horizontal intrusive sheets of dolerite in the Eccra Series, which run regularly for miles, are probably of this late Karroo age.

In the central Transvaal (Springbok Flats)¹⁹² the lava-flows, known as the *Bushveld Amygdaloid*, cover an enormous area. The rock is an amygdaloidal olivine-basalt, and has been proved to overlie the Bushveld Sandstone Series of Upper Karroo age⁵⁰. The lava-flows are nearly 1000 ft. thick. Along the Messina road²²⁶, and eastwards of it, limburgites rest on the uneven surface of the Bushveld Sandstone and are associated with nepheline basalts.

There is also a huge development of lavas in the Lebombo Mountains^{28 46 193} of Swaziland along the Portuguese frontier. These lavas rest on the sedimentary Upper Karroo beds, and consist at the base of a series of flows of basalt and melaphyre, mostly amygdaloidal, of which the normal type is a fine-grained amygdaloidal basalt varying in colour from purple to black. These flows are pierced by masses of augite-granophyre. Overlying them is a series of acid lava-flows (rhyolites, felsophyres, etc.), and again above these (in Portuguese territory) come more basic rocks. The series of amygdaloidal basalts near Komati Poort attains a thickness of nearly 500 ft.

Correlation of the Karroo Beds.—The precise European equivalents of the various divisions are not a matter of certainty, but the Dwyka tillite and Upper Dwyka shales are probably referable to the Upper Carboniferous, the Eccra and Lower Beaufort to the Permian, the Upper Beaufort to the Lower Trias, and the Molteno and Red Beds to the Upper Trias or Rhætic, while the Cave Sandstone and Volcanic Beds may also belong to the Rhætic¹⁰⁸ or are later.

THE COASTAL SYSTEM (CRETACEOUS).—The Cretaceous beds in the Union of South Africa represent horizons ranging from the Wealden to the Danian. In the Cape Province, Natal, and Zululand the sparsely developed Cretaceous rocks have been called the *Coastal System*³. Two main divisions are shown to exist by the fossil evidence, i.e. a lower one known as the *Uitenhage Series*, and an upper one called the *Umtamvuna* or *Umzamba Series*. They are both confined to the marginal or coastal regions. No Cretaceous beds are known from the interior of South Africa.

(1) **The Uitenhage Series**⁹⁴.—This series is restricted to the Cape Province, where it occupies rather wide areas between the folded Karroo beds and the sea-coast; the youngest rocks on which it rests are the Eccra beds, from which it is separated by a great unconformity. The series corresponds to the Wealden and Neocomian and is well developed between Grahamstown and Port Elizabeth¹⁸⁸. In the valleys of rivers flowing into Algoa Bay⁸⁴ it has been divided into the *Sunday's River Beds*, the *Wood Beds*, and the *Enon Beds*. These were at one time thought to form successive stages, but the evidence now available seems to indicate that they are merely local facies of one stage. For the whole series is subject to considerable horizontal variation in character

and thickness, the beds are impersistent, and one or more divisions may be locally absent. The maximum thickness of these beds must be over 2000 ft. Only one palaeontological stage is represented by the whole Uitenhage Series, for the marine fauna found at different horizons possesses a generally uniform character¹⁶⁶, and this fact forbids any but a local classification of the beds. It is usually referred to the Neocomian.

In Pondoland, near Port St. Johns¹³⁷, there is a small patch of these Uitenhage beds at the mouth of the *Umgazana* River, consisting of conglomerates with a lenticle of limestone containing many typical mollusca and some plant-remains; 25 miles away there is a coarse conglomerate consisting chiefly of large boulders of Karroo dolerites, sandstones, etc., known as the *Embotyi beds*^{70 86 187 152}, which are likewise of Uitenhage age.

(a) **The Enon Beds** are found at the base of the series throughout the district, though beds of the same type continued to be formed in the Uitenhage district^{84 89} during the deposition of the Sunday's River Beds.

The Enon type consists of sandstones, marls, and conglomerates, but the beds vary much in thickness and nature. The conglomerates in the upper part of the Zwartkops Valley are over 1000 ft. thick (though usually they are only about 50 ft. thick), and red clays, sands, and pebble-beds occur associated with them. The Enon conglomerate consists of quartzose pebbles and boulders, chiefly of rocks of the Cape System closely packed together, and imbedded in red sandy clay; the beds have yielded casts of *Estheria* and fragments of wood. The Cretaceous beds are represented by the *Enon Conglomerate* in the Oudtshoorn-Uniondale area, and also in the Baviaans-Kloof-Gamtoos¹³ and Ashton-Worcester area.

(b) **The Variegated Marls and Wood Beds** overlie the Enon Beds in the northern part of the district, and amount locally to 1000 ft. in thickness. Yellow sandstones, thin calcareous bands, oyster beds, and saliferous shales—all of fresh-water or estuarine origin—comprise the group. In one place, Dunbrodie, on the Sunday's River, there occur marine mollusca like those in the overlying Sunday's River Beds, but hundreds of feet below the top of the Wood Beds. Large tree-trunks, many leaves, and other plant-remains occur in the Wood Beds, chiefly consisting of cycads, conifers, and ferns. Amongst the cycads there are many species of *Zamites*, and amongst the ferns are *Onychiopsis mantelli*, and *Cladophlebis browniana*, both of which are known in the Wealden of Sussex. Though there is a mixture of Wealden and Jurassic forms, yet on the whole the balance is in favour of a Wealden age³¹. Several species of plants are identical with, or closely allied to, Indian forms occurring in the Upper Gondwana beds. The lamellibranch found in the limestone bands is known as *Psammobia atherstonei*. Dinosaurian remains^{54 105} have been discovered in these beds on the Bushman's River, and this deposit may be of the same age as the Tendaguru beds of Tanganyika, which have yielded similar reptiles (see p. 79-80).

(c) **The Sunday's River Beds**^{94 186} are essentially of marine origin, but the plant-bearing beds below pass up into them. They consist of shales, clays, calcareous sandstones, conglomerates, and limestones. In the Sunday's River Valley the beds form a wide synclinal trough with generally low dips. They are frequently crowded with lamellibranchs which form the predominant group in the fauna, and the genus *Trigonia* is particularly abundant. The ammonite genus *Holcostephanus* (*Eogersites*) is also common^{137 138 139 266}. Only a very small proportion of the species of mollusca can be identified with European forms. But all the typical species are allied to Cretaceous forms, especially to Neocomian and Aptian species. Representatives of these marine beds occur also in Tanganyika.

Amongst the fossils may be mentioned^{32 33 266} the following :—

Holcostephanus (Rogersites) atherstonei Sharpe, *Holcostephanus (Rogersites) wilmanæ* Kitchin, *Bochianites glaber* Kitchin, *Crioceras (Distotoceras) spinosissimum* Hausm, *Hamites africanus* Tate, *Belemnites africanus* Tate, *Actæonina atherstonei* Sharpe, *Monodonta hausmanni* Neum. and Hol., *Natica uitenhagensis* Kitchin, *Cucullæa kraussi* Tate, *Astarte herzogi* Goldf., *Seebachia bronni* Krauss, *Ptychomya complicate*, Tate, *Trigonia herzogi* Goldf., *Trigonia conocardiiformis* Krauss, *Trigonia tatei* Neum. and Hol., *Trigonia vau* Sharpe, *Trigonia ventricosa* Krauss, *Modiola rubigei* Tate.

In the Knysna estuary west of Uitenhage the thickness of the Uitenhage Series is over 600 ft., while farther west at Mossel Bay³³⁸ the beds are probably over 1000 ft. thick, and rest on an uneven surface of Cape and pre-Cape rocks. In the Olifants River district⁶⁹ the series consists of a red conglomerate followed by a white conglomerate, with brown sands and red and blue marls at the top, probably representing the Wood beds of the Uitenhage district.

In the Swellendam area there is a basin of Uitenhage beds, and west of it there are two more isolated basins, one being situated near Worcester, where post-Uitenhage earth-movements have affected them. Between the Langebergen and Zwarteborgen there is a large area occupied by this series, and elsewhere there are patches of it; in places the beds have been folded or faulted into the older rocks. The lithological characters of these rocks vary, but they are chiefly conglomerates, clays, and sandstones, which in some places yield the typical fossils.

The occurrence of post-Uitenhage folding movements in the coastal belt of the Cape Province is now well established⁶⁹, and the general direction of the folds seems to be identical with that of the older post-Karoo disturbances.

(2) **Upper Cretaceous.**—Upper Cretaceous beds, ranging from Aptian to Montian in age, are represented by marine deposits largely developed in Zululand^{222 343a} along the Pongola River²⁰⁶. The fauna from them has been described by Van Hoepen^{126 138}, Spath^{136 139}, Vanzo²⁰⁷, Rennie²⁰⁶, and others¹³⁸, the stratigraphy by Dietrich²²². Senonian beds have been struck in bore holes near Durban²¹⁹ and have yielded typical ammonites. The Upper Cretaceous beds occur in small patches along the coast in Pondoland^{70 86}, Natal, and Zululand^{55 64-66}, whence they extend into Portuguese territory. There is no evidence of the occurrence of the Uitenhage Series in those localities where they are found, and they rest unconformably on much older beds. In Pondoland they are faulted down against the Table Mountain Series.

The Upper Cretaceous beds at the north end of False Bay, Zululand, contain fossils indicating an Albian-Cenomanian age^{34 64 65 206}. The beds are calcareous arkoses and shales, and contain many species of cephalopods (*Acanthoceras*, *Puzosia*, *Forbesiceras*, *Phylloceras*, *Turrilites*, *Nautilus*, etc.). Many of the species are identical with those from the Utatur Beds of southern India, and a similar cephalopod fauna is also found in northern Madagascar and on the islands off Graham Land in the Antarctic Regions.

In Pondoland^{70 86 126 137 139 152 260 267} the *Umzamba Beds*, which are of Senonian age^{126 138}, occur on the river of that name, and consist of shelly limestones, black shales, and hard sandy calcareous clays, with a conglomerate at the base. The beds lie almost horizontal, and at the mouth of the river they are only about 13 ft. thick. They contain many fossils, chiefly mollusca, comprising many lamellibranchs, gastropods, and cephalopods. A large

number of foraminifera, ostracods, and some echinoids have also been described from them. Amongst the fossils may be mentioned⁸⁵ the following :—

Cephalopoda : *Hauericeras gardeni* Baile, *Hauericeras rembda* Forbes, *Pseudophyllites indra* Forbes, *Gaudryceras kayei* Forbes, *Schloenbachia* (*Pseudoschloenbachia*) *umbulazi* Baile, *Mortoniceras soutoni* Baile, *Anisoceras subcompressum* Forbes, *Hamites indicus* Forbes, *Faculties sulcatus* Baile. Lamellibranchiata : *Trigonoarca capensis* Griesb., *Pectunculus africanus* Griesb., *Trigonia shepstonei* Griesb., *Trigonia elegans* Baile, *Pecten* (*Chlamys*) *amapondensis* Griesb., *Meretrix euglypha* Woods. Gastropoda : *Pyropsis africana* Woods, *Pseudomelunia sutherlandi* Baile. Echinoidea : *Pseudodiadema griesbachi* Woods, *Hemiaster forbesi* Baile.

The beds are referred by Woods³⁵ to the Upper Senonian, and the fauna bears a great resemblance to that of the Ariyalur and Valudayur Beds of southern India, many of the species being identical. Beds with a similar fauna occur in Natal, Zululand³⁴, Mozambique³⁷, and Madagascar.

The Manuan Creek beds and Umkwelane Hill deposits^{55 66} of Senonian^{136 261} age in Zululand have special faunistic affinities with the Trichinopoli Group of India.

On the coast of Alfred County, Natal, there are calcareous shales, arenaceous limestones, and conglomerates yielding many of the same fossils as Pondoland, together with the reptiles *Liodon* and *Cimoliosaurus*, and fish-remains belonging to the genera *Lamna*, *Gorax*, *Ozyrhina*, and *Scapanorhynchus*.

At Need's Camp on the Buffalo River, near East London, there are shelly and polyzoan limestones which have yielded a few lamellibranchs and many polyzoa, indicating a Senonian or even Danian age, and in the Albany and Alexandria divisions similar beds occur, forming part of Schwarz's 'Alexandria Formation.' But the upper limestones of the Alexandria Formation about two miles distant are of Eoc-Pliocene age (q.v.).

On the west coast of the Cape near Bogenfels³³⁰ Upper Cretaceous marine beds occur, containing a species of *Placenticerus*. This is the farthest south locality for Upper Cretaceous beds on this coast.

With regard to the geographical distribution of the Cretaceous fauna possessing this South African faunas, it is important to note that it has been found not only in Madagascar, southern India, and the Antarctic, but also in Borneo, Japan, Vancouver, California, Chili, and New Zealand, pointing to the existence of one huge bio-geographical province in Upper Cretaceous times³⁶. (See 'India'.)

Upper Cretaceous (Non-Marine).—Bones of a dinosaur named *Kangnasaurus coetzeei* Houghton, allied to *Camptosaurus*, have been discovered in clayey sand with calcareous concretions in a well about 30 miles north-east of Steinkopf in Namaqualand on the Orange River.

It is possible that the oldest of the Kalahari deposits, such as certain dark red quartzitic sandstones, pink flagstones, and pale shales, may be of Cretaceous age¹⁶³.

Diamond-bearing Deposits^{256 257}.—It was previously thought that the diamond-bearing pipes in South Africa represent the latest phase of volcanic activity in Karroo times, but it is now held that they belong to the late Cretaceous^{163 228 257}, or even Tertiary period, for near Heidelberg (Cape) they are seen to pierce Cretaceous beds. (See below.) These pipes are best known at Kimberley^{29 60 344}, where they pierce beds of pre-Karoo and early Karroo age.

The diamond-bearing pipes consist essentially of vertical conical or cylindrical holes drilled through the solid rocks and filled with a serpentinous or

micaceous breccia. It is not the case that these necks or pipes are everywhere surrounded by Karroo beds : thus in the Pretoria district they pierce only pre-Cape rocks, the latest here being the Pretoria Series, but younger overlying beds may have been removed by denudation. The depth to which these pipes descend is unknown, but they have been proved to about 2000 ft. The pipes or funnels in cross-section are of a more or less circular or oval shape, and vary much in size; the Premier Mine in the Transvaal is the largest and covers many acres. The pipes decrease in diameter below so as to be slightly funnel-shaped. As regards their origin, they are generally regarded as the vents of volcanoes which have been filled up from below by volcanic mud and agglomerate, including fragments derived from the encasing walls, and from deep-seated sources²²¹. The surrounding beds have their edges occasionally turned up as if by pressure from below.

The diamond-bearing pipes^{120 221 228 256} occur not only at Kimberley but at several other localities in the Cape Province¹⁰¹, in Griqualand West⁷⁸, in the Orange Free State at Jagersfontein and Kofnefontein, and in the Transvaal north-east of Pretoria¹⁸. A pipe of kimberlite has also been opened in East Griqualand^{79 186}, and similar pipes, though not carrying diamonds, are found in South-West Africa (*q.v.*). Kimberlite pipes²²¹, some of which carry diamonds, are also now known in central and east Africa. (See under 'Tanganyika'.)

The diamond-bearing deposit itself generally consists of a serpentinous breccia of a tough soapy nature and greyish blue colour when fresh (the 'blue ground' of the miners), becoming yellow in its weathered condition ('yellow ground'). It is composed chiefly of fragments and grains of many minerals^{211 257 273}, including olivine, garnet, ilmenite, chrome-diopside, enstatite, bastite, and biotite, and, to a less extent, of magnetite, chromite, picotite, perovskite, tourmaline, zircon, rutile, kyanite, corundum, and diamond. These minerals seem partly derived from granites and gneisses, but largely from ultrabasic rocks. The cementing material consists of serpentinous clayey matter with much calcite and other carbonates, and chlorite. Rock-fragments of various types occur in it, and include pieces of the walls of the pipe, both of sedimentary and igneous origin, as well as numerous boulders of igneous rocks derived from greater depths. In the Kimberley³⁴⁴ Mine the chief rock-fragments in the upper part of the pipe are shale and amygdaloidal diabase, while on the lower levels quartzite, granite, quartz-porphry, and diabase are predominant. Blocks of ultrabasic rocks also occur. There are two classes of kimberlite : (1) the Basaltic type, which is the commoner type, containing green olivine, diopside, garnet, ilmenite, etc., in a serpentinous matrix ; and (2) the Micaceous type, occurring chiefly in fissures and dykes and differing from the first type by containing less magnesia and more potash ; it is represented in the Lower Harts and Vaal River valleys and at Boshof, Orange Free State.

It has been thought by some geologists that the pipe material itself is a true eruptive lava which has solidified *in situ*, and subsequently suffered decomposition and alteration. According to this theory the brecciated character is due to movements during consolidation, and this pipe-rock (frequently termed 'kimberlite'¹⁸⁵) is thought to have arisen from a deep-seated ultrabasic magma which has incorporated fragments of the shattered surrounding and underlying rocks in forcing its passage upwards through them²⁹. The diamonds themselves are therefore regarded as xenocrysts which have formed during the consolidation of the magma.

According, however, to Bonney⁸⁰ and others, the 'kimberlite' was originally a volcanic breccia composed chiefly of fragments of peridotites and other ultrabasic rocks and their minerals of deep-seated origin, together with some

fragments of the surrounding sedimentary rocks. The funnel was blown out by a paroxysmal eruption, and the hole thus formed was filled by this shattered material through which heated waters subsequently ascended during the solfataric stage, producing many secondary changes in the breccia. The diamonds, according to this view, have not been formed in the pipe, but are derived from the deep-seated ultrabasic rocks of which they formed original accessory constituents. The kimberlite magma is considered by Holmes²¹¹ to agree chemically with melilite basalt²⁸⁷. The rocks and minerals in it by their helium ratios indicate a late Cretaceous age²⁵⁷.

By some other geologists the diamonds are believed to have been formed in eclogite concretions in the blue ground itself.

The diamonds from the different mines have distinctive characters; they occur in crystal forms varying much in size, and are frequently broken.

Volcanic Pipes of Doubtful Age.—The melilite-basalt²⁶⁷ and agglomerate necks in the Sutherland area of Cape Colony^{87 95 267} may be of Cretaceous or later age. In some cases these vents are filled with purely igneous material, while in other cases the fragments are all of sedimentary rocks, and there is every graduation between the two extremes. Some of these necks form conspicuous hills. The breccia-filled pipes or necks form a special class, of which Saltpetre Kop in the Sutherland district forms a conspicuous hill, and grouped round it are 19 satellite pipes and many dykes filled mostly with breccias and tuffs. The contents vary greatly, but chiefly consist of sedimentary Karroo rocks with fragments of granite, gneiss, etc. The materials have been impregnated in places by carbonates of lime and magnesia, barite, limonite, and silica. Similar melilite-basalt^{8 255 267} pipes occur in southern Namaqualand³¹⁷ and at Heidelberg and Bobertson in the western part of the Cape Province. At Heidelberg²²⁸ the pipe which pierces beds of the Uitenhage (Cretaceous) Series occupies an area of 300 by 220 yds., and consists of a rock with a glassy groundmass containing crystals of perovskite magnetite, melilite, augite, and phenocrysts of fresh olivine. In Namaqualand the kimberlite pipes³²⁰ are largely filled with fresh-water clays of Pleistocene or Recent age containing plant-remains and bones of frogs, the original material having been removed by erosion.

Tertiary.—The only parts of the Union of South Africa where beds occur which may be definitely referred to the Tertiary are the Cape Province and Zululand. But in Portuguese territory east of Swaziland there is a considerable development of marine beds, and along the coast of South-West Africa fossiliferous marine deposits of Eocene and Miocene age (q.v.) also occur⁶⁹.

(1) **Eoc-Pliocene.**—On the Buffalo River, at Need's Camp, near East London, and in the Zwartkops region, there is a series of marine limestones (forming part of Schwarz's **Alexandria Formation**¹⁰⁷) which contain species of *Ostrea*, *Melina*, *Venus*, *Tellina*, *Cardium*, *Voluta*, *Conus*, etc., which, according to Newton⁵⁵, indicate a Mio-Pliocene age. But it is now held that the Alexandria Formation embraces a great part of the Tertiary and includes beds of Eocene as well as Miocene and Pliocene age. The molluscan fauna is now held to be mostly allied to that of Europe. On the west coast of the Cape Province¹⁴⁵ Tertiary beds of Eocene to Pliocene age occur with a somewhat similar marine fauna. In the Tertiary deposits of the south-eastern districts of the Cape Province Haughton¹³³ has described other Eocene fossils, including the foraminifer *Orthophragmina*, in limestones 450 ft. thick and 650 ft. above sea-level; the Upper Eocene genus *Discocyclus* has also been recognised.

The **Bredasdorp Formation**¹³⁴, which occurs in two belts from the Gouritz River to Port Beaufort and from the Potteberg past Bredasdorp to near Cape Agulhas, rising to a height of 700-800 ft. and 400-500 ft. thick, consists of pebble beds with some marine shells, sandstones, and limestones; at Saldanha Bay it is the representative of the Alexandria formation¹⁶⁸.

(2) **Pliocene** ?—To the north-east of Knysna a series of sands, clays, and lignites occurs on the high coastal plateau filling up hollows of an old surface of the Table Mountain Series. The beds are estimated to be over 200 ft. in thickness, and in places rise to a height of 1300 ft. above sea-level. Their precise age is undetermined, and so far only coniferous wood and leaves have been found in the lignite and sand. It is possible that some of them are of the same age as the Bredasdorp beds.

(2a) In Zululand along the shore of Lake St. Lucia, Lake Sibayu, and Kosi Bay, there is a series of muds, clays, and blue shales containing marine fossils and land mammalia, reptiles, and fish. The mammals include extinct species of *Hippopotamus*, antelope, rhinoceros, elephant, buffalo, etc., and suggest a Pliocene age. Overlying these beds are false-bedded sands, occasionally containing carbonaceous bands.

Pliocene (or Pleistocene) Deposits.—(a) In the Transvaal³⁹ the tooth of *Mastodon* and other mammalian remains have been found in the diamond bearing gravels of the Vaal River, near Barkly West; probably these gravels are of Pleistocene age. From the gravels of the Vaal^{142 290 352} and Limpopo valleys and watersheds and of the Knysna³²¹ district there have been described several species of elephant of which the oldest is *Archidiskodon andrewsi*, together with other genera and species, including pygmy species of *Pilgrimia*, and other mammalia, amongst which an extinct genus of giraffe, *Griquatherium*¹⁴², has been found on the Vaal River. The gravels belong to various stages of the Plio-Pleistocene and Stone age⁶⁶². An Upper Pliocene terrace at Cornelia, Orange Free State, has yielded other extinct species of elephant and remains of hippopotamus. In the caves of the Transvaal³³⁹ there are the remains of various species of mammalia, some of which are extinct, and these deposits may be of Pliocene rather than Pleistocene age. Near Bloemfontein human implements associated with extinct species of mammals have been found beneath peat.

(b) In the southern part of the Cape Province³ there is an older series of gravels, sands, ferruginous clays, and surface-quartzites, occurring at high levels up to 1200 ft. or more, and forming the remnants of an elevated plain⁹³. They rest unconformably on all the older deposits, including the Uitenhage Series, and form terraces and plateaus. The gravels become coarser near the mountains, and pebbles and boulders of Table Mountain Sandstone (up to 5 ft. in diameter) are the most conspicuous constituents. The matrix is usually a reddish ferruginous sandy material, and by the secondary deposition of silica it has frequently become cemented so as to pass into a hard fine-grained rock forming the typical surface-quartzite^{88 90 91 104 216}, which is widely spread in South Africa. This rock may reach a thickness of ten feet, and on the Cape Flats passes down into a sandstone, and that again into loose sand. Rarely the surface-quartzite contains seeds of *Chara* and shells of *Limnæa*. It is frequently largely calcareous in composition, and passes into a sandy limestone. These surface-quartzites^{216 263}, often called *silcretes*, are usually fine-grained rocks breaking with a conchoidal fracture and composed of detrital quartz grains and other minerals cemented together by secondary chalcedonic silica which in some cases has replaced a clayey²¹⁶ or calcareous²⁶³ matrix. By an increase of ferruginous material they merge into lateritic

ironstones. Irregularly-shaped cavities lined with chalcedonic quartz are a characteristic feature. In the country north of the Orange River such surface-quartzites have a wide, though not uniform, distribution⁸⁹, and their formation probably covers a long portion of Tertiary and Quaternary times.

Amongst other surface-deposits which have been probably forming since late Tertiary times (though some may be much earlier, according to Passarge¹⁰⁴) are the *laterites*, or lateritoid rocks⁸¹⁵, which have been derived from many kinds of rocks by weathering and bacterial action, as well as by the concentration of hydrated iron oxide in the surface layers or subsoil. But their present position is often apparently due to transport by wind or water. The widespread accumulations of loose sand (e.g. in the Kalahari Desert^{104 199}) may even partly date back to Cretaceous or earlier times owing to the long exposure of the land-surface to weathering^{286 311 332 341}. There are surface marls and loose gritty deposits in this area, the age of which is uncertain³¹¹. There are also the ¹ surface-limestones^{199 216 315 361} or calcareous tufas of the interior of the Cape Province, the Orange River State, and the south-west Transvaal, and the silicified limestones which have been produced by replacement of the carbonates by silica, and are largely developed in the Kalahari Desert^{104 199}, and in that part of South Africa with a rainfall less than 2.5 inches per annum. Such surface-limestones³¹¹ tend to be developed upon older limestone and dolomite beds, such as on the Campbell Rand Series¹⁴⁹, but also occur on the Dwyka Series and on basic igneous rocks and schists, but rarely on granites or arenaceous rocks. There are thick sheets on and at the base of the Kaap plateau and around Ventersdorp, but they especially spread over huge areas in the Kalahari^{104 199 311} and have often suffered silicification. Passarge¹⁰⁴ classified the Kalahari surface deposits into five successive groups, and Maufe has correlated them with some of those at the Victoria Falls, his 'Pipe Sandstone' corresponding to Passarge's 'Kalahari Limestone Group B'; he found it separated from the lowest Group A by an unconformity and also unconformably overlain by Group C. Rogers²⁸⁶ has given a more recent description of these deposits and the solid rocks below them³³².

The calcareous tufa^{29 149 275} of the interior, which may attain a thickness of 60 ft. (e.g. on the Harts and Vaal Rivers³⁵²), is believed to have been formed either in brackish-water lakes during a time of greater rainfall, or by capillary action or springs, the carbonate of lime having been brought up to the surface of the land by ascending water, and derived from the older calcareous beds of the Karroo and pre-Cape formations. In one calcareous diatomaceous deposit in the Kuruman district⁸⁸ living and extinct fresh-water mollusca have been found, including *Gorbicula fluminalis*, a species living now in the Nile, and found in the older river-gravels of Cambridge. The calcareous deposits on the Kaap Plateau¹⁴⁹ are of special interest because they have yielded at Taungs, in Bechuanaland, the skull of an extinct anthropoid *Australopithecus*^{140 162 274 275}, together with remains of baboon, antelope, etc.³³³; this deposit is by some referred to such an early age as Lower Pliocene.

The high-level gravels are occasionally auriferous⁹⁸.

The newer gravels and alluvial deposits occur in Cape Colony at various levels between the high-level deposits and the recent deposits of the existing rivers. The river terraces occur at various heights and contain fragments of the older surface-quartzites. Near Johannesburg the gravels yield Eolithic, Palaeolithic, and Neolithic implements. The abundant Palaeolithic implements from the diamondiferous gravels of the Vaal River⁸⁵² belong to the Pniel culture.

The coastal limestones^{134 263} of the western and southern coasts of Cape Colony are chiefly of æolian origin, and frequently show some bedding; they may reach a thickness of 70 ft., and form striking hill-ranges and dunes

over 500 ft. high. Fragmentary marine and land shells and bones of mamalia are found in them¹⁸⁵. Most of them belong to Recent species, but an extinct horse, *Equus capensis*, occurs; in Zululand similar deposits have yielded species of elephant (*Elephas zulu*) and hippopotamus (*Hipponderosi*)¹³⁵. Near Durban²¹⁹ the so-called *Bluff Series* of calcareous sandstones contains fragmentary marine mollusca and is referred to the Pleistocene. The origin of the coastal limestones is due to the infiltration of carbonate of lime into loose calcareous drifted sands.

Salt-pans in the interior of Cape Colony occur chiefly in the north and north-west portions⁸⁸; they are most numerous in the outcrops of the Dwyka formation, and are abundant also on the Ecce beds. They are usually circular or oval in shape, and vary in size up to several miles in diameter, as in the Makarikari Salt Pan in Bechuanaland¹⁷⁶. The erosive action of the wind²⁹ is regarded as the chief factor in the excavation of these hollows, and the evaporation of the rain and sub-surface water is believed to have led to the deposition and incrustation of the salt. The Pretoria Salt Pan¹⁷⁸, which is now usually regarded as an explosion-crater, having below the lake in it a volcanic pipe, has been suggested to be of meteoric origin and due to the impact of a meteorite. Its edges, consisting of grits of the Pretoria Series, are upturned, and its floor is sunk 200 ft. below the level of the surrounding flat country. It pierces the Red Granite, and the materials filling the pipe consist of masses of granite, some blocks of norite, and of alkaline syenites and porphyry, together with a dolomitic breccia. The mud in the centre of the pan is impregnated with chloride and carbonate of soda, and the saline clays go to a depth of 230 ft.

Raised beaches^{91 263} on the coast containing Recent marine mollusca are found in the Cape Peninsula up to 100 ft. above sea-level, and at lesser heights elsewhere, pointing to elevation of the land in Recent times. In Natal^{64 308} and Zululand similar beaches occur, indicating Pleistocene and Recent strand movements.

Coastal terraces are well developed in Pondoland²⁶³. But the Raised beaches in the Cape Province have been most closely studied and their contents are best known. The 100-ft. beach on the west coast of the Cape Province contains *Ostrea prismatica* and other mollusca no longer known to be living off the coast^{145 196}. It varies in height on the south and south-east coast owing to recent warping of the ground. A most persistent beach¹⁶⁶ at a level of 20 ft. exists along or near the whole coast containing living shells, and there is another Raised beach at about 15 ft. These indicate pauses in the elevatory movement. Krige¹⁶⁶, however, recognises much earlier terraces or beaches formed during the uplift of South Africa, the movement beginning in early Tertiary times and being of an intermittent nature. The chief resting stages are marked by terraces at 4000, 2500 and 1000 to 800 ft. respectively, and smaller ones roughly at 550 to 450 ft. and 250 to 150 ft., as above mentioned. The last three stages are partly covered with marine Mio-Pliocene sediments. The emergence continued so as to lay bare part of the Agulhas Bank, and that this occurred between late Tertiary and late Pleistocene is shown by the drowned river estuaries being silted up with Pleistocene or Recent deposits. Finally, emergence has left strand-marks and river terraces at elevations of 50 to 60 and 20 ft. respectively, the latter being a widespread phenomenon. The evolution of the South African coast-line^{164 166 308} was not completed till post-Pleistocene times, the Agulhas Bank and Continental Shelf crossed by drowned river-valleys representing the latest extension of the land, which was probably not submerged till after the Glacial period. High-level terraces also occur inland, such as the conspicuous one^{133 134} along the northern flank of the Winterhoek, sloping from a height of 2600 ft. in the west to about 1500 ft.

at the east end of the range. On it lies a deposit of large angular blocks of Table Mountain Sandstone set in a siliceous cement. This terrace is traceable over a large area in the south of the Cape Province; the precise period of its formation is uncertain, but it seems to mark the edge of the plain of marine erosion on which the Alexandria formation was laid down.

Many of the hot-springs which occur in Cape Colony rise in Table Mountain Sandstone areas, and are not apparently connected with the folds or faults affecting that formation. Others arise from nearly horizontal Karroo beds.

TECTONIC HISTORY OF SOUTH AFRICA

There are four main tectonic lines in the Union of South Africa along which earth-movements have taken place at various times, and they are marked by folds or dislocations. Passarge¹⁰⁴ terms them (1) the Damara Series, trending from N.N.W. to S.S.E.; (2) the Cape Series, running east and west; (3) the Kaffraria Series, following the coast-line in a general S.W. to N.E. direction; and (4) the Lebombo Series, running from south to north. In many cases igneous rocks also have been poured forth or intruded along these lines.

The precise sequence and correlation of the various pre-Cape formations have hardly been sufficiently established to enable us to give a detailed account of the geological history of the Union of South Africa during the long pre-Cambrian or pre-Devonian period. But the great unconformities which separate the different groups of beds and the successive movements of folding and fracture which they have suffered make it obvious that a complicated series of events took place, and that the lines of folding, directions of pressure, and regions of uplift or depression underwent considerable changes before the deposition of the beds of the Cape System. According to Du Toit¹⁶³ earth-movements resulting in the folding and faulting of the strata have followed upon (1) the Archaean, (2) the Waterberg, (3) the Karroo, (4) the Lower Cretaceous, and (5) the Lower Tertiary, while warping of the coastal districts and minor movements of upheaval or subsidence, unaccompanied by folding, have occurred in post-Tertiary and Recent times¹⁶⁶. The whole tectonic history of South Africa, including the folds and the faults, has been traced by Born^{200 202}, Demay²⁰¹, Krenkel^{269 310}, Hennig²⁸⁹, Pencki¹⁴⁸, Rogers³²², and others. The effects of these movements on the present physiography of the country have been described by Dixey²¹⁴, and more especially by King²⁸⁸.

The chief period of mountain-building in Cape Colony commenced after the deposition of the Ecca Series, and went on at intervals until the deposition of the Uitenhage Series, that is, between the Permo-Carboniferous and the Lower Cretaceous. It involved the Cape System as well as the Lower Karroo beds of the marginal districts.

The folding in the southern parts was produced by a thrust from the south against the block of old rocks, the beds being thrown into a series of parallel folds, and the anticlines being sometimes overturned towards the north and the overthrust faults dipping to the south. The great strike-faults (such as those of Worcester and the Congo) running east and west on the south side of the most crumpled ranges have downthrows reaching at least 10,000 ft. Some of these faults mark a later stage of movement than the folding, and the great Worcester fault was begun in Triassic or early Jurassic times, but was not completed till after the Lower Cretaceous. This Worcester fault²⁶⁸ bounds the Langebergen on its south-western side, and brings up the Table Mountain Sandstone obliquely to the main axes of folding. Near Robertson it has a throw of 12,000 ft., and is the greatest fault in the Cape Province. The Enon Conglomerate is affected by it.

On the western side of the South African horst the folding may have begun earlier, and was less intense, and the folds are more symmetrical. The folding here was the result of pressure from the west instead of from the south, and the two systems of folds meet in the country between Karroo Poort and Cape Hangklip. The Cedarberg folds which run N.N.W.-S.S.E. from False Bay began in Middle Carboniferous (pre-Karoo) times, but the Cape folds, which radiate from the same area and run in a general E.N.E.-W.S.W. direction, were partly formed in Permian-Triassic or Jurassic times.

The precise limits of this period of folding and the extension of the movement into the interior cannot at present be ascertained, but neither the Beaufort nor the Stormberg beds have been recorded from the folded belt, so that the movements must have ceased before the Middle Karroo. The main outlines of South Africa were marked out by the great marginal dislocations subsequent to the Stormberg period, and were probably produced during Jurassic or even Cretaceous times¹⁰⁴, like the Worcester fault.

Later disturbances affecting the Uitenhage beds occurred in post-Cretaceous times, following approximately the direction of the earlier movements, but there was some cross-folding (as in the Bavian's Kloof district), resulting in the formation of basins frequently containing isolated patches of Cretaceous beds. No great crumpling or over-folding, however, took place at this time.

In the north-east of the Cape Province in Pondoland¹³⁷ and also in Natal, we find faults running parallel to the coast, dropping down the Upper Cretaceous beds against the Table Mountain Series, but there is no direct evidence connecting these dislocations with the post-Uitenhage folding which took place farther south⁵³. Schwarz⁵³ was of opinion that this faulting of the south-eastern margin of the

continent was connected with the movements which formed the Rift Valleys of East Africa.

Over the interior there is no sign of any intense folding since pre-Karoo times, the Karroo beds lying mostly horizontal or only slightly inclined or gently undulated. Faulting has, however, affected these beds in some places to a considerable extent, and is particularly apparent north of the Union in the Zambesi region (see 'Rhodesia').

According to Rogers³²² and Born²⁰² the 'Great Escarpment' is a denudation feature and not due to faults or folds, for it is quite independent of them and traverses formations of various ages from the Archaean to the Karroo. The Drakensberg^{148 295} is, however, related to the Quathlamba fault, according to Penck. The Great Escarpment runs at varying distances from the coast continuously from the northern Transvaal southwards through Basutoland and Natal, but then curves westward through the Cape Province, finally bending to the north-west through Namaqualand into South-West Africa, where its continuation is not distinct.

Former land connections.—Reference has above been made to the view that a great Austral continent, which has been termed Gondwanaland, existed in Karroo times. But in what way it disappeared or broke up and at what period this took place is a matter of conjecture. Wegener's 'continental drift' theory is adopted by Du Toit^{130 164 277 307}, and is a plausible explanation in itself, but Van Hoepen²⁴⁹ adopts a different interpretation, and the old idea that the landmass was submerged after fragmentation is still held by some geologists.

ECONOMIC GEOLOGY²⁴⁷

Gold²⁵⁷.—The chief centre of gold production is the Rand, and the mode of occurrence of the gold in the Witwatersrand Banket beds has been sufficiently described above (pp. 128-132).

In the Swaziland System in the northern province gold may occur (1) as a constituent of basic igneous intrusions, or in their crushed and metamorphosed representatives; (2) in quartz-veins; (3) in the magnetite-quartzite slates; (4) in the conglomerates; (5) in granites. In the Barberton district the distribution of the reefs in this System clearly depends on the proximity of the 'Older Granite'¹¹⁸; they are of the nature of contact deposits, but there are also fissure veins. In the Murchison range the gold is found associated chiefly with antimony ores. It may occur in fissure veins or replacements or impregnations along zones of shattering or shearing, traversing various kinds of rocks^{173 184 213 247}

The Transvaal System has gold irregularly distributed in the Black Reef Series, but chiefly in the Dolomite Series, where it is

found in cross-reefs or flat-reefs, the latter apparently interbedded, but really epigenetic in origin⁴⁴. In the Lydenburg district at Pilgrims' Rest¹⁷⁵ the gold occurs in bedded veins associated with the Black Reef Series, Dolomite Series, and Pretoria Series. The reefs consist of partly replaced country rock with quartz and pyrites.

In the Table Mountain Series of Knysna, Cape Province, quartz-reefs carrying gold in association with ores of other minerals (zinc and lead) are known, and alluvial deposits derived from them are spread over the neighbouring flats.

Platinum¹²² 123 124 168 172 247 -This mineral occurs chiefly as segregations in basic or ultrabasic rocks, such as norite and dunite, in the Bushveld Complex (*q.v.*), forming stratified bands, and is associated with other minerals; it also occurs as contact-metamorphic deposits. Interesting deposits of an unusual character occur in brecciated quartz-lodes occupying faults of post-Karoo age near Naboomspruit in the central Transvaal. The platinum is there found in irregular patches²⁴⁷. In some parts of the Transvaal it is also found in alluvial deposits. The mineral may be alloyed with other members of the group, such as palladium, as in the Merensky Reef in the Lydenburg district. In Griqualand East it is found with the copper-nickel ores in the Insizwa gabbro-norite intrusive mass.

Copper.—Deposits of copper occur in the granitic gneisses of Messina^{49 247 331} and in the northern Transvaal along well-defined fissures of variable width. The ore is chiefly copper glance with bornite, and the lodes dip at high angles, striking rather obliquely to the banding of the gneisses. Its occurrence appears to be connected with a persistent dolerite dyke.

The chief deposits in the Cape Province which have been worked are those in Namaqualand²⁸² in the neighbourhood of Ookiep. Dykes of intrusive rock varying in composition from anorthosite to hypersthene cut across the 'Archaean' gneiss with a nearly east-and-west strike. The commonest types of these intrusives are mica-diorite and norite. The ore is chiefly bornite with a smaller amount of chalcopyrite, and is either disseminated in the dykes or collected into pockets, but the bornite is as much a constituent of the rock as is the hypersthene. The deposits are frequently regarded as true magmatic segregations^{61 62 282}.

The Insizwa^{109 191 284} ore-deposit on the boundary between East Griqualand and Pondoland is composed of nickeliferous copper and has been thought to resemble in character the Sudbury deposit in Canada, and to be Ukwisi due to magmatic differentiation of an intrusive mass. The base of the mountain range of Insizwa consists of Lower Beaufort sandstones, mudstones, and shales,

which are succeeded by hornfelses. Overlying them comes a great sheet of intrusive gabbro, 2000-3000 ft. thick, with ultrabasic phases. The most important of the types of ore-deposits connected with this sheet is the mineralised norite or picrite, containing disseminated sulphides of copper, nickel, and iron, and occurring as a zone at the base of the gabbro.

True fissure veins carrying copper (and usually also silver) occur in the Pretoria Series near Pretoria, and copper-silver lodes or mineralised zones along zones of Assuring occur in the Red Granite of the Bushveld Complex.

Iron^{229 326}.—There are certain important haematite deposits of the Lake Superior type, being secondarily enriched sedimentary ores. These occur in the Rustenburg district on the Crocodile River¹⁵⁷. The haematite in them is unusually pure and high-grade. In the Griqua Town Series¹⁵⁷ of the pre-Cape Rocks in Griqualand West³⁴⁷, there are extensive iron-ore deposits resulting from the concentration of iron-oxides, and they form hills 400 ft. high. The bodies of ore are breccias consisting of fragments of the banded siliceous rocks cemented together by haematite and silica, and they lie in solution-cavities or fissures in the underlying dolomitic limestone. In the Postmasburg area^{186 203 350} there are many scattered deposits belonging to two types, one consisting of ferruginous banded iron-stones with haematite comprising 95 per cent, of the rock. This type is represented by the Blink Klip breccia in which the Lower Griqua Town beds are highly brecciated, and all stages can be seen from the unaltered rock up to solid masses of iron ore. The other type is a conglomerate in which the ore-bodies are discontinuous and vary from 50 ft. thick to thin layers of pebbles.

The 'calico rocks' (magnetite-haematite schists) of the Swaziland System also contain a high percentage of iron in many parts of South Africa, but are highly siliceous¹¹⁸. In the Zoutpansberg district there are massive aggregates of haematite and magnetite in the gneiss and amphibolite. But the banded ironstones in the Swaziland and Witwatersrand Systems are too siliceous to be used as iron ores.

In the Transvaal System some of the quartzitic sandstones of the Pretoria Series are highly impregnated with magnetite, and are traceable from the Pretoria district into the Lydenberg district. These are³²⁶ the principal iron deposits in the Union.

Stratiform magmatic segregations of titaniferous iron ore⁶³ in huge quantities are found in the norite of the Bushveld Igneous Complex.

In the Ecca Series of the Karroo System in many parts of Natal and the Transvaal there are interbedded seams and lenses of

excellent iron ores, in places converted into magnetite by contact with dolerite sills.

Certain beds of the Karroo System in the Middelburg district are heavily impregnated with haematite, passing into pure ore; in Natal, interbedded mangiferous iron ore occurs in the same System.

Nickel^{158 204 212 241 247 298}.—The nickel deposits occur in the Bushveld as isolated masses of irregular size and shape in the bronzitite within the lopolith of norite constituting the lower portion of the Igneous Complex. The masses are composed in part of disseminated sulphide ore and in part of massive sulphide ore, chiefly pentlandite, with pyrrhotite and chalcopyrite. In the Pilandsberg the pipe-like ore-bodies are vertical in the harzburgite and bronzitite and are due to replacement²⁰⁴. In East Griqualand and Pondoland there are nickeliferous ore-deposits^{191 212}. The great intrusive sill of gabbro-norite at Insizwa^{109 191 284} (Mount Ayliff) contains nickel and platinum as well as copper. The mineralised zone of nickeliferous pyrrhotite is near the base of the intrusive sheet of basic igneous rock close to the contact with the Lower Beaufort beds. The ore occurs either as massive sulphides or is disseminated through the olivine hyperite. In places the nickel contents are 5 per cent. In the Barberton district²⁴⁷ two nickeliferous minerals occur as a tabular ore-body in schists of the Swaziland System and contain 15-25 per cent, of nickel.

Tin.—The Waterberg tin-fields^{45 341} in the Transvaal are the most important in the Union, though other tin areas occur on the Pretoria-Bushveld boundary, and there are large alluvial deposits in Swaziland. In the Waterberg tin-fields the Red Granite of the Bushveld Plutonic Complex and the lower part of the Waterberg System are the most important tin-bearing formations. In the Red Granite the cassiterite deposits occur (1) in the form of roughly cylindrical pipes; (2) associated with irregular bodies of altered granite; (3) as irregular disseminations in slightly altered granite; (4) as impregnations along well-defined lines of fissure; and (5) associated with pegmatites and quartz-veins. The pipes are the most remarkable form^{155 247}, usually occurring in groups, and descending at various angles into the granite; they range from 2 to 12 ft. in diameter, and have been proved to a depth of over 400 ft. There is sometimes an outer zone of tourmaline-quartz rock, but the main mass of the pipe is a slightly altered granite passing into a greenish highly silicified rock. In the shales and quartzites of the Lower Waterberg System the deposits are found in lodes and more or less definite lines of fissure, or as irregular patches or pockets, often connected by fissures or determined by planes of

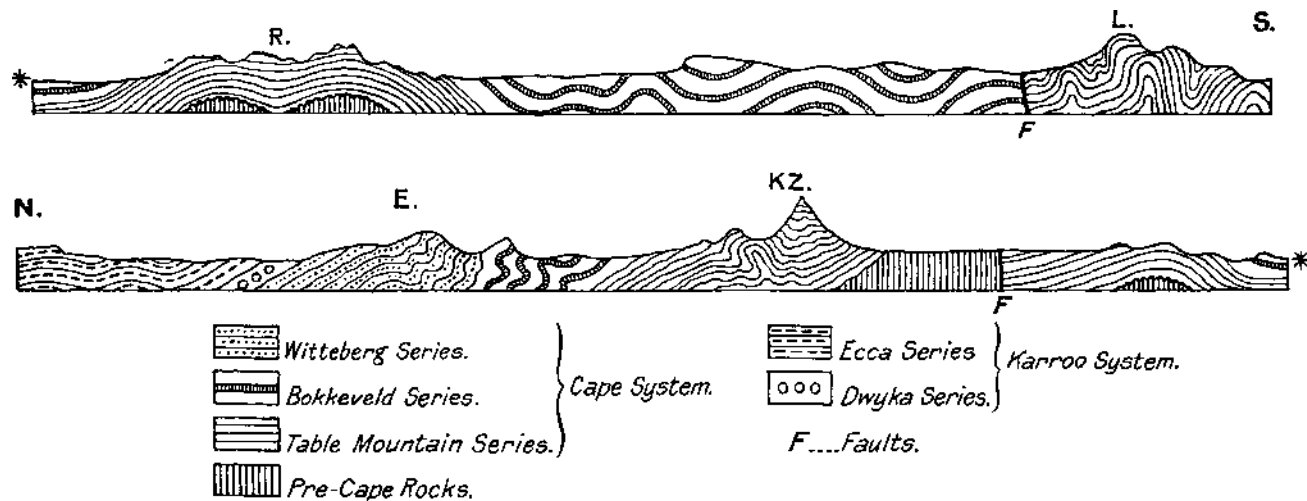


FIG. 6.—DIAGRAMMATIC SECTION FROM THE LANGEBERGEN ACROSS THE FOLDED BEDS OF THE CAPE SYSTEM (based on sections by the Geological Survey) (vertical scale exaggerated).

stratification. The deposits in the Rooiberg and Pretoria Series are of the character of well-defined lodes connected by large irregular replacements and usually lie along the bedding planes of the felspathic quartzites which enclose them. It is probable that the fissures were formed during the intrusion of the granite. The ore-bodies contain a variety of minerals in addition to the tin²⁴⁷.

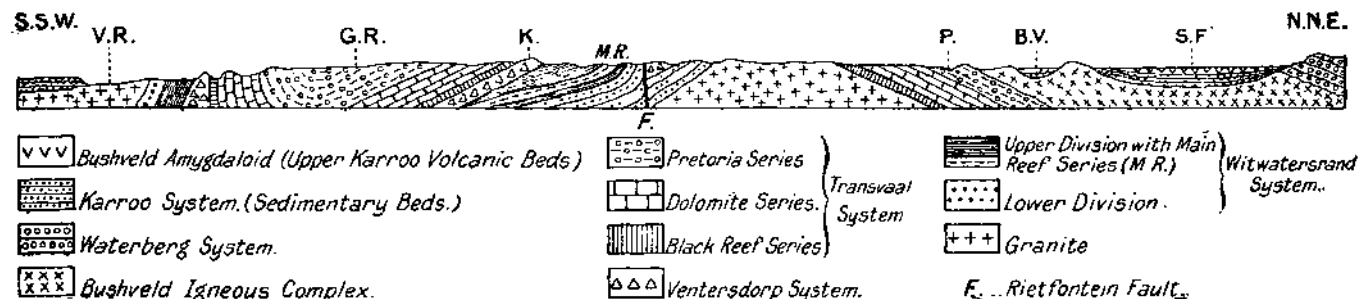
The Swaziland alluvial deposits at Embabaan are gravels which occur in the granite-country, and seem to be derived from the lodes which are known to exist in the quartzites and schists of the Swaziland System where intruded by pegmatites or granite¹¹⁸.

In the Kuils River district in Cape Colony there are tin-bearing veins in a grey granite associated with acid micaceous dyke rocks, but the principal deposits here are alluvial.

Tungsten occurs as schelitic in the Waterberg district in association with the tin ore, and at Stavoren¹⁵⁵ and Rooiberg in the Bushveld; it is also found in some gold-quartz veins in granite at Leydsdorp and near Barberton and in Swaziland. *Wolframite* is found in Natal in hornblende-schist. In the Gordonia district north of the Orange River wolframite occurs in quartz veins in gneiss near their contact with granite; in the Steinkopf Native Reserve in Namaqualand scheelite is found in quartz pegmatites.

Lead and Zinc.—The most important deposits of these ores occur in the Dolomite Formation¹⁶⁷ in the Zeerust-Marico²⁶² and Mafeking district; they are more or less intimately associated with manganese and sometimes with fluorite and barite. The minerals occur in circular areas in the dolomite or chert from a few chains to 100 yards in diameter forming true pipes, or as small aggregates of crystals scattered through the dolomite. The galena is due to replacement of the dolomite along definite lines of fracture. The most productive silver-lead lode deposits in South Africa are those near Argent Station²⁴⁷ on the Johannesburg-Witbank railway, where norite and pyroxenite of the Bushveld Igneous Complex are intersected by parallel veins containing galena, argentite, native silver, zinc blende, and copper ores. In the Pretoria Series quartz veins containing argentiferous galena occur near Belfast and west of Lydenburg.

Manganese.—The most important deposits of this mineral are in the Postmasburg area in the Griqua Town Series 185 186 203 209 217 347. they occur in two belts, and consist of several ores, chiefly psilomelane and braunite. They are supposed to be replacements of chert, hæmatitic breccia, conglomerate, and shale^{318 349 350}. In the eastern belt the ore forms isolated masses of various sizes and shapes, distributed irregularly through a siliceous breccia with irregular



W.

REFERENCES

V.R. Vaal River.
G.R. Gaterand.

K. Klipriversberg.
P. Pretoria.

B.V. Bushveld.
S.F. Springbok Flats.

FIG. 7.—DIAGRAMMATIC SECTION FROM VREDEFORT TO SPRINGBOK FLATS (based on sections by Molengraaff and others).

junctions between the underlying dolomite and the overlying Blink Klip breccia; it even occurs in the same breccia. In the western belt the ore deposits may be of a bedded nature associated with the conglomerate and shales overlying the dolomite, or may cut across several horizons of these beds, forming the so-called Gamagara Series²⁴?

Titanium.—Ilmenite occurs disseminated in the old granite and gneiss and in the Gordonia pegmatites, but is also distributed in a granular form in some of the sands on the Natal coast from which it could be recovered.

Uranium.—The uraninite of the Gordonia pegmatite has been used by Holmes²⁹⁴ to correlate, by means of the lead ratios, the Upper Pre-Cambrian rocks of Southern Africa, and to determine their age.

Molybdenum.—Near Potgietersrust peculiar modifications of the Red Granite are found in which the rock becomes a mixture of tourmaline, quartz, mica, molybdenite, arsenopyrite, fluorspar, etc., in varying proportions. In the Waterberg and Pretoria districts the mineral is found in pegmatites and granite. Molybdenite occurs also in several parts of the Transvaal in association with cassiterite in the tin deposits of the Bushveld Igneous Complex.

Antimony.—Stibnite is found in lenticular veins in schist near Leydsdorp in the Murchison Range^{173 181}, and near Barberton in auriferous reefs. All the antimony minerals are auriferous and argentiferous, and the deposits are chiefly worked for their gold and silver contents.

Chromite.—This mineral occurs in intimate association with the norites, pyroxenites, and other ultrabasic rocks in the Bushveld Plutonic Complex in the Transvaal^{223 337}. It may take the form of a well-defined zone near the margin of the igneous rocks as in the Rustenberg district¹⁰⁶, or lie in parallel bands in heavy pyroxenite rocks as in the Pilgrims' Rest district⁴⁴, or occur as isolated masses of chromic and magnetic iron ore. It is frequently the case that platinum is associated with it¹⁰⁶. The 'chromitite' * bands or seams in the central Transvaal vary greatly in thickness and conform to the general pseudo-stratification of the pyroxenites, gabbros, or anorthosites; they vary in thickness from 1 in. to 6 ft. In Natal the chromite occurs as irregular bands at Isitilo in serpentine or is disseminated in the rock.

Coal¹⁵⁶.—All the coal deposits occur in the three divisions of the Karroo System, but the chief coal seams are in the Ecca Series in the Transvaal and Natal. There are some less important seams in the

* See note on p. 105.

Beaufort Series in Natal and in Zululand which are of poorer quality. The Stormberg coal seams occur in the Cape Province and are of less importance. The commonest kind of coal in South Africa is of the semi-bituminous character, but ' gas ' coal is found in the Witbank area. Anthracitic coals are specially represented in Natal.

The thickness of the coal measures varies greatly ; at Witbank its maximum is 450 ft., and at Brakpan 130 ft., but at Komati Poort it is 3200 ft. The Highveld or south-eastern Transvaal⁴⁸ coal-fields are the most important and comprise the following separate areas : (1) Witbank area, which is the most important producing field in the Union ; (2) Ermelo-Carolina area ; (3) Springs area ; and (4) Vereeniging area, which extends into the Orange Free State. There are a number of smaller less important or undeveloped areas in the Transvaal. The middle division of the Eccra Series²³⁸ contains the principal coal-seams, but, owing to the northward overlap of the beds of the series, the seams appear progressively at higher horizons in the Eccra Series. The number of workable seams is small, and, while in Natal and the south-eastern Transvaal they average 4-6 ft. in thickness, they increase considerably to the north, and in the great coal basin of the South Rand there is a main seam near Heidelberg of 53 ft. In this region²³⁸ the coal measures cover very extensive areas, and are fairly continuous (Vereeniging, Ermelo, Belfast).

In Natal the intrusive igneous dykes and sills have frequently converted the coals into semi-anthracite (Newcastle and Dundee coalfields¹). In Natal the chief coalfields are the Klip River field near Glencoe, the Vryheid field, and the Utrecht-Paulpietersburg field.

In the Cape Province, as stated, the coal seams occur in the Upper Karroo, and the workable ones are confined to the Molteno Beds. But they are thin, impersistent, and poor in quality. One of the chief fields is at Indwe⁹⁶.

Corundum¹⁵⁴.—In the old crystalline rocks of the northern and north-eastern Transvaal corundum is widely distributed. It occurs either as loose crystals in surface deposits due to weathering of the solid rocks, as in the Zoutpansberg, or as primary deposits in reef-form in vertical bands or dykes of intrusive pegmatite or aplite in basic or ultrabasic rocks or in granite or gneiss. Nearly all of it is common corundum.

Diamond¹¹¹.—The mode of occurrence of diamonds at Kimberley and in the Transvaal has been described (p. 149) in connection with the post-Karoo or post-Cretaceous intrusives, but the stones also occur in the Vaal River gravels of Pliocene or Pleistocene age. The diamondiferous pipes³²⁸ pierce rocks of all ages up to and including the Lower Cretaceous. The most important are those of Kimberley,

Pretoria, Jagersfontein, and Koffiefontein. It is believed that they are situated on lines of Assuring as they occur mostly in groups. The great Premier Mine³⁴⁵ near Pretoria consists of a group of kimberlite pipes having an irregular oval shape over 2900 ft. in length. The country rock is felsite, except on the north-east side, where it is of quartzite³⁴⁵. Huge isolated masses of the Waterberg quartzite occur in the 'blue ground,' which is also traversed by remarkable carbonate dykes. The felsite belongs to the Bushveld Igneous Series. Diamonds have also been found in the Witwatersrand beds²⁴⁷, and are there of detrital origin; they likewise occur in the Molteno beds of the Upper Karroo. Such diamonds must have had much earlier origins. The alluvial diamondiferous gravels occur not only along the Vaal River but along the Orange and Limpopo Rivers, though erratically and in pockets. The solution-hollows in the dolomite of the Ventersdorp¹⁸⁸ and Lichtenburg³⁴⁴ plateau region, which are filled with angular fragments of chert and worn pebbles of quartzite, jasper, etc., have yielded many diamonds. Some of the rich deposits are of the nature of 'placers'; others are high-level or low-level terraces or river beds.

In Little Namaqualand¹⁷⁰ near the mouth of the Orange River and in the neighbourhood of Port Nolloth and farther south at Buffels River on the coast, the older Raised shingle beach, containing *Ostrea prismatica* and other mollusca, has yielded immense numbers of diamonds. In Alexandra Bay the gravel forms a strip 8-100 ft. wide at a height of 110-135 ft. above sea-level. All this part of the Atlantic coast of South and South-West Africa (*q.v.*) possesses similar diamondiferous deposits of ages ranging from early Tertiary to Recent. The source³¹⁷ of these coastal diamonds is somewhat problematical.

Emeralds²⁴⁷ occur in the Murchison Range¹⁸¹ and in biotite schists at or near contact with pegmatites in the Letaba area, north-east Transvaal.

Grossularite, the South African jade, is a lime-garnet occurring, associated with chromite, in the gabbro of the Bushveld Igneous Complex, about 40 miles west of Pretoria. It is found in bands up to 18 inches thick.

Asbestos^{112 233 347}.—The blue soda-amphibole asbestos (crocidolite) is mined especially in the Prieska and Hay districts¹⁰⁰ in the Cape Asbestos belt, which is at least 240 miles in length. It occurs as layers interbedded with the banded jaspers and ironstones of the Lower Griqua Town Series. It is generally oxidised and silicified, becoming of a golden-brown colour. In the Pietersburg and Lydenburg districts a peculiar iron amphibole asbestos (amosite) occurs in a banded siliceous ironstone at the base of the Pretoria Series, and in

the former district crocidolite also is found with the same mode of occurrence as in the Cape belt. Fibrous asbestos (chrysotile) is also known in connection with basic or ultrabasic rocks in the Barberton and Carolina districts in the Transvaal. At Kaapsche Hoop²⁵⁸ in the Barberton district and in Swaziland the chrysotile occurs in serpentine intrusive in the Moodies Series ; it is similarly found near Piggs' Peak.

Mica.—The muscovite-bearing pegmatites of the Malelane field and Olifants River in the Murchison Range¹⁸¹ seem to form part of the Palabora intrusive complex⁴³, and are of considerable importance.

Fluor-spar¹⁶⁷ occurs in the Dolomite of the western Transvaal as large irregular bodies or veins and lenses, but in the central Transvaal as veins in the Red Granite of the Bushveld Complex.

Phosphates.—In the Zoutpansberg²⁶² apatite occurs locally in massive bands in the pegmatite and schist belt of the ancient crystalline rocks. In Saldanha Bay there are beach and scree deposits composed of boulders and weathered fragments of the granite of the neighbourhood which have been phosphatised by guano and suffered sub-aerial weathering; they are of great extent and value⁵⁶.

Phosphatic deposits of Karroo age are interbedded with the Upper Ecca Shales in Natal, near Ladysmith.

Nitrates¹¹⁹.—In the districts of Prieska and Hay, nitrate salts are found filling interstices and pockets in the 'krantzies' and cliffs of the Lower Griqua Town Series. The layers of nitrate rarely exceed a thickness of 2 in., and usually lie in the bedding-planes of the hard siliceous shales or 'jaspers,' extending inwards from the surface to a depth of 25 ft. or more. Nitrate of potash is the most abundant salt. It is believed that the potash has been derived from the shales and that the nitrates have been formed by organic and atmospheric agencies.

Oil-shales^{227 314 353}.—Most of the oil-yielding shales (torbanites)³⁵³ in South Africa belong to the Ecca Coal Measures, and are almost identical with the Scottish torbanites ; they are not persistent over large areas, occurring in scattered patches in the region between Breyton, Ermelo^{314 353}, Wakkerstroom, and Utrecht²²⁷. The beds of economic value vary from a few inches to over 2 ft. in thickness. The so-called 'oil-shale' of the Impendhla area, Natal, is more of the nature of cannel-coal.

Magnesite.—Magnesite occurs in the Transvaal near Male-

lane^{83 118} in numerous veins up to several feet in diameter, traversing a belt of serpentine in the Jamestown Series associated with the granitic and schistose rocks of the Swaziland System.

Building Stones and Ornamental Stones²³¹.—Amongst the building stones used in South Africa the Table Mountain Sandstone is largely employed in the Cape, and the Waterberg Sandstone in the Transvaal. From several parts of the Karroo System throughout South Africa, sandstones for building purposes are obtained; amongst them may be mentioned the Rosetta stone of the Ecca Series in Natal and the Transvaal. Granites and other igneous rocks of the pre-Cape formations are quarried to some extent in the Cape and Transvaal.

Marbles and ornamental stones are rare or little worked. The Belfast marble is a serpentinised calcareous bed in the Pretoria Series in the Transvaal. The Buffelsdoort marble occurs as a mass of dolomite in the Red Granite of the central Transvaal. The Marble Hall rock occurs likewise as a mass of the Dolomite and Pretoria Series in the Bushveld granite, N.E. of Pretoria. The travertine and onyx marble near Port St. Johns rest on a platform of Dwyka tillite and were apparently deposited by a hot spring.

Siliceous materials are obtained from the silcretes in the Mossel Bay and Riversdale districts, as well as from the quartzites of the Pretoria and Black Reef Series.

Clays are chiefly obtained from the Karroo system, and are of residual nature. But marine and estuarine clays are much used near Port Elizabeth.

Water¹⁸⁰.—Owing to the frequent droughts, the water supply and its sources are of great importance in the Union. A review of chief water-bearing formations has been given by Frommurze¹⁸⁰. Structure, topography, and rainfall are the chief factors in determining the water-bearing supplies. There are no large artesian basins, but small artesian areas are found in the Karroo beds of the Gibeon district in South-West Africa, in the Dolomite Series, in the Springs and Barkly West districts, and in the crystalline rocks in Namaqualand. In the Uitenhage area conditions are favourable for artesian bores in the Cretaceous rocks. The water-bearing properties of the areas of Crystalline rocks depend on joints, degree of decomposition, rainfall, and other factors. The Ventersdorp System is an important water-bearer, but the Dolomite gives the best yield, and is traversed by many underground streams. The Karroo beds give a variable amount of water, dependent on the structure, nature of the rocks, and position of intrusive sheets, dykes, and masses. Much information about springs and wells is

also give by Du Toit¹⁶³, together with references to the scattered literature on the subject. Warm springs are usually associated with igneous dykes or lines of fault. The Dolomite is the chief source of the cold springs in the Transvaal and Griqualand West.

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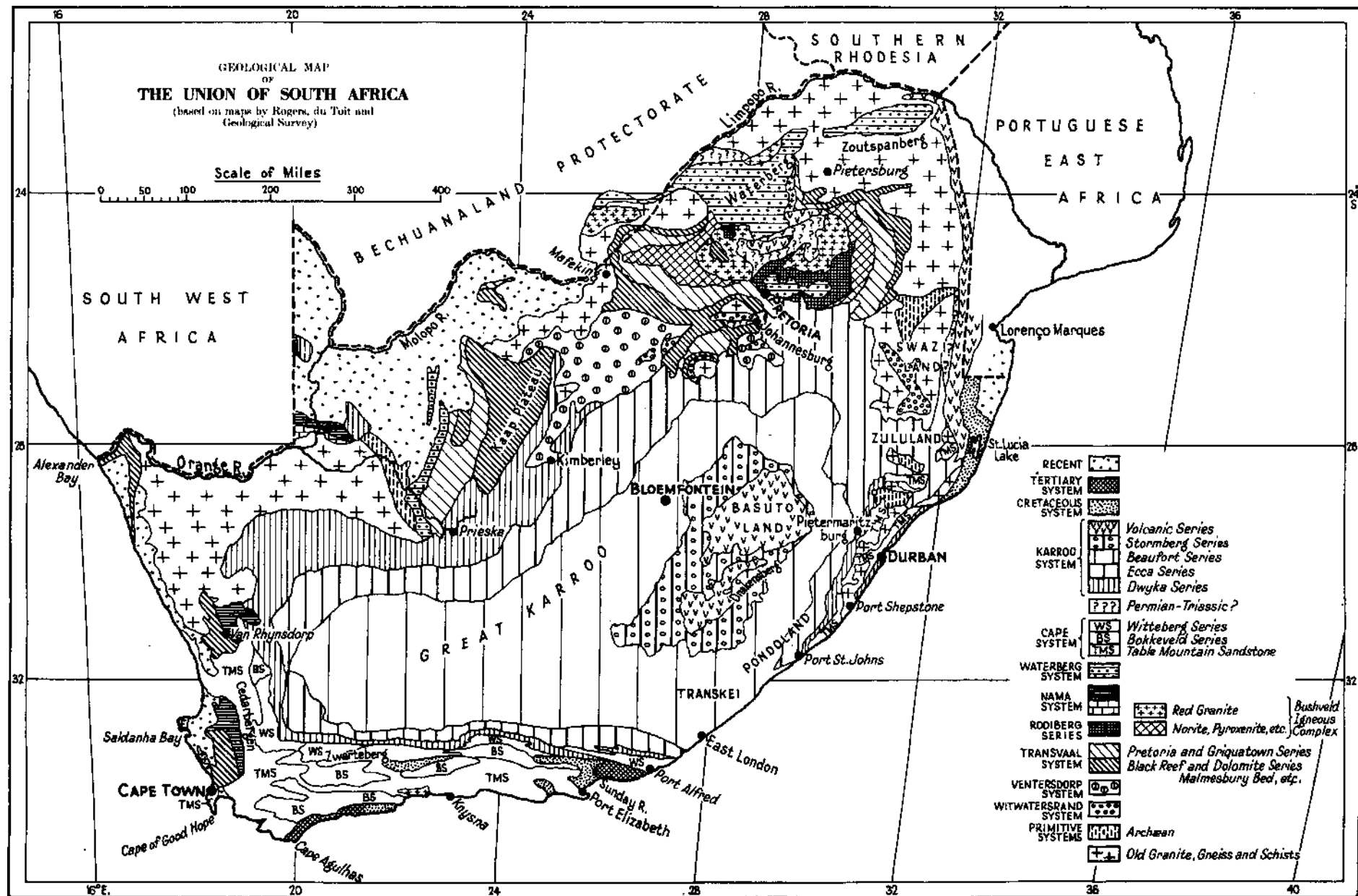


FIG. 9

SECTION II.—SOUTH-WEST AFRICA (Mandated to the Union of South Africa)

General Characters and Relations^{137 63}.—South-West Africa, which has an area of over 320,000 sq. miles, stretches from the Orange River northwards up to 17° 23' S. lat., and mostly forms part of the main South African Plateau, and of the interior basin of the Kalahari. The edge of the plateau is not here clearly marked by distinct scarps as it is in Angola and in the Cape Province, though there are broken ranges of mountains along it in the north and south¹⁷. The surface of the interior upland or plateau slopes gently inland into the Kalahari Basin, and is diversified by isolated heights and ranges, while there extends along the whole coast a low-lying strip of land of varying width constituting the coastal desert or so-called Namib. The geological formations which enter into the structure of the country are fundamentally the same as those in the Cape Province and the Transvaal, but are mainly of pre-Karoo age. They comprise representatives of the Fundamental Complex^{2 8}, and of the Nama and other Pre-Cambrian Systems of the Cape; while the Karroo beds³ are developed in the southern portion of the Mandate, occupying large areas in the districts of Warmbad, Keetmanshoop, Hasuur, and Gibeon, but isolated patches of them elsewhere indicate the former wider extent of this formation, and it is now proved that the rocks of the so-called Kaoko Formation (see below) near the north-western frontier are also of Karroo age^{16 53}.

Along the Luderitzland littoral^{6 25} Tertiary and Recent marine deposits are specially developed, while superficial accumulations, which have been in process of formation since the elevation of the main African Plateau, are widely spread over the interior.

DESCRIPTION OF THE FORMATIONS

(1) The Fundamental Complex¹²⁸⁹²⁸.—Ancient gneissoid and granitic rocks, exhibiting a great variety of lithological types, occupy immense areas in the southern, western, and central portions of South-West Africa. Augen-gneiss, composite gneisses, and gneiss-granite are widespread, and are associated with schists and altered sediments. Distinct groups of rocks of widely different ages are present amongst these schists and altered sediments, and they are separated by marked unconformities, though they are mostly folded together in an intricate manner. A great belt of these foliated and metamorphic rocks extends from the coast across Damaraland. In the north and centre these are known as the *Abbabis System* below, and the *Damara System* above.

The *Abbabis System*^{28 39} is found on the southern side of the Khomas Mountains in the Windhoek district, and consists of quartzites, marbles, phyllites, gneisses, and mica-schists. It is intruded by gneisses, pegmatites,

and amphibolites, and is separated by a strong unconformity from the overlying *Damara System*^{28 39 47 68}, a period of earth-movements and folding of the strata having occurred before its deposition.

The *Damara System* occupies large areas in Damaraland^{28 30} and also composes the Khomas Mountains⁶⁸. In the Windhoek region⁶⁸ the *Damara System* consists of the following groups in descending order :—

Khomas Series.

Marble Series.

Tillite Series.

Quartzite Series and basal conglomerate.

The whole system amounts in thickness to more or less than 35,000 metres, according to Gevers. The thickest formation consists of phyllites or shales in the Khomas Series which, in the Auas Mountains, includes a middle group of quartzites. The Marble Series includes graphite schists, and the Quartzite Series contains some muscovite schists. The Tillite Series is known as the *Chuos tillite*^{22 47 68 75} and occurs, between the Quartzite and Marble Series, or at some lower horizon²² in western Damaraland⁶⁸ and elsewhere, and may reach a thickness of 1500 ft. In the Rehoboth and Windhoek³⁹ areas^{47 68} the deposit seems to have been laid down by floating ice. The matrix of the tillite where argillaceous has been converted into a biotite schist, but where arenaceous it has become a dense siliceous rock. The boulders and pebbles in it are faceted and embrace a great variety of rocks, including gneiss of the Abbabis System. The laminated schistose rocks overlying it suggest glacial varves. Gevers^{22 39 75} considers it to be the oldest glacial bed in South Africa. The whole *Damara System* is compared by him with the Swaziland System. The Marble Series forms great belts in the western and north-western portions of Damaraland, but there are also some important bands in Bastardland, and in the Namib. Layers of phyllite and hornblende-schist are intercalated with the marbles, and metamorphism of the marbles by intrusive granite is a common feature, for after the formation of the *Damara System* there were great intrusions of granite and gneiss⁴¹, and in the Auas district⁷⁸ three different types or phases of granite intrusion have been described.

These intrusive granites occupy large areas in the Fundamental Complex, and at least two distinct periods of intrusion occurred in pre-Nama times. In the western portion of Damaraland the so-called Salem granite belongs to the first period, and is a grey porphyritic biotite-granite. The second period of intrusion comprises several types of granite, and is likewise represented in the neighbourhood of the Erongo Mountains³⁶.

In Great Namaqualand the granites form several ranges of hills or isolated elevations of the 'inselberg' type. The formation of veins of pegmatite, aplite, and quartz ('reefs'), the latter of which accompany faults or crush-zones, was associated with the intrusion of the granites in various places.

Many other igneous intrusions cut through the rocks of the Fundamental Complex, and they include quartz-porphyry, essexite, quartz-diorite, granite-porphyry, diabase, and olivine-diabase⁶⁷.

A later formation, known as the *Bastard or Phyllite Series*^{39 68}, is folded into the Marble and other series of the *Damara System*; it is only found in some places in the northern part of Bastardland, but probably occurs also in the Kaokoveld and elsewhere. It consists of greyish-blue phyllites with intercalated beds of quartzite, and its relations with the older series are undetermined. It has been correlated with the Witwatersrand System of the Transvaal. Before its deposition igneous intrusions took place together with eruptive effusions^{39 68}. Following the *Bastard Series* in the Windhoek district another series of rocks, the *Kudis Series*, has been recognised by Gevers³⁹, marked by fluvial conglomerates.

In the western part of Great Namaqualand a series of porphyrites, amygdaloidal melaphyres, tuffs, and conglomerates resting unconformably on the Fundamental Complex, and succeeded unconformably by the Nama System, has been named the *Konkip Formation*. This formation^{11 12 15 22 25 48}, the precise correlation and position of which is somewhat doubtful, is found in the Luderitz coastal district and far to the north of Auas. The lowest beds are conglomerates, limestones, quartzites, and slates, and they are succeeded by acid and basic eruptives, conglomerates, breccias, and tuffs. The eruptives comprise diabase and porphyrites, and are penetrated by quartz-veins containing argentiferous copper ores and some gold. The uppermost series consists of sandstones, conglomerates, and breccias. Beetz^{11 15} correlates the middle igneous group of the Konkip formation in the Namib with the Ventersdorp System of the Transvaal and lower part of the Koras Beds of the Cape, but the lower group of the Konkip he would ascribe to the Congo Series and the Witwatersrand System, and the upper group with the upper part of the Koras beds. The conglomerate at the base of the Konkip is probably of glacial origin. Gevers²², on the other hand, regards the Konkip System as equivalent to the Keeweenawan Series of the Canadian Shield. These correlations are, however, disputed.

(2) **The Nama System**^{2 8}.—This system, which we have described in the Cape Province of the Union, covers large areas of the interior of South-West Africa as well as of the north-western and south-western portions of the Cape Province. It is supposed by some geologists to be the equivalent of the Transvaal System of central South Africa.

It rests unconformably on all the older formations above described, and is divisible into a lower and upper division. The succession varies from place to place, and the upper members frequently overlap the lower. Distinctive names have been applied to the various subdivisions.

The *Basal Beds*, which reach a thickness of nearly 3300 ft. in some areas, consist of conglomerates, breccias, grits and arkoses, all containing much fresh felspar, and also of sandstones. The conglomerates are frequently very coarse and contain boulders and pebbles of a great variety of rocks. In certain places in the central and southern regions of South-West Africa on the Orange River and in the Rehoboth district there is a glacial tillite^{15 25 70} at the base of the Nama System associated with clay slates. It occurs south of the railway to Luderitz in the Southern Namib. The boulders included in it in the eastern part consist almost entirely of granites, gneisses, pegmatites, etc., of the basement rocks, but in the western part they are of limestone and quartzite. Beetz¹⁵ correlates this tillite with the *Numees tillite* of the Union of South Africa farther south on the Orange River. In the Klein Kharas Mountains the Nama tillite is also found⁷⁰. In the Gobabis district the Basal Beds reach a thickness of 3000 to 3500 ft., and in the Erongo Mountains they are especially well displayed. They are also exposed in the great escarpment at Nosib in the Grootfontein district, but in the Kaokoveld they seem to be poorly developed. In the southern portion of Great Namaqualand⁸ the Basal Beds are succeeded by massive quartzites with subordinate sandstones, normally only about 300 ft. thick, and known as the *Kuibis Beds*⁸. Some doubtful fossils, and one considered to be allied to *Archceocyathus*, have been recorded by Gurich^{23 37 42} and others from these beds. There was a period of folding²⁹ in the central portion of South-West Africa after the Archaean, and again after the Pre-Cambrian, the direction of which was N.E.-S.W.

In the Gobabis district and Bastardland alternations of quartzite and black limestone ('schwarzkalk') indicate the close connection of this formation

with the overlying *Schwarzalk Series*⁸, which is developed above the Kuibis Beds of Great Namaqualand, and varies from 160-1300 ft. in thickness ; it consists of a dense bluish-black limestone with layers of shale, sometimes bituminous, in its upper portion, but no chert. In the Windhoek district^{39 68} the beds referred to the Nama System have a wide distribution and are known as the *Gobabis System*⁶⁸, the lower part of which probably belongs to the Kuibis Series and consists of quartzites and sandstones of a deep red or chocolate colour, together with sedimentary breccias and conglomerates. The upper part is composed of pale-coloured quartzites and sandstones, with an intercalated horizon of calcareous shales, limestones, and dolomites corresponding to the *Schwarzalk* of the Gobabis district.

In the Grootfontein and other districts of the northern area, including the Kaokoveld, but especially in the Otavi Mountains, the equivalent of the *Schwarzalk* is known as the *Otavi Dolomite Series*^{7 13 83}. It is generally composed of two dolomitic horizons separated by some ferruginous shales or slates, with layers of dense white chert, which vary much in thickness, commonly intercalated in the Dolomite. No determinable fossils have been discovered. In the Kaokoveld⁴ this Dolomite Series is locally over 3000 ft. thick. The formation is clearly of marine origin, and may be correlated with the Dolomite Series of the Transvaal System of the Transvaal. It contains mineral deposits of great importance^{53 54} (see below). A glacial tillite occurs in the Otavi Mountains in this formation⁷¹.

The *Schwarzalk* is overlaid conformably in Great Namaqualand by a series of greenish sandstones and shales known as the *Schwarzrand Beds*, 650 to 1000 ft. thick. But in the Gobabis district, and in the northern portion of South-West Africa, there is a break in the sedimentation between the Dolomite and the succeeding beds of the upper division of the Nama System. The conglomerates and arkoses in the latter contain pebbles of the underlying Dolomite, and may be correlated with the Lower Waterberg Beds of the Transvaal.

Overlying respectively the *Schwarzrand Beds* in Great Namaqualand and the *Otavi Dolomite* in the Grootfontein district is yet another group of unfossiliferous sediments described as the *Fish River Series*, from its occurrence in that river valley, and occupying very wide areas. In Great Namaqualand it consists of a thickness of over 1000 ft. of pink, purple, and red sandstones and shales, many of the sandstones showing alternations of pink and yellow or grey layers, and frequently being current-bedded. A curious dark heavy rock composed almost entirely of grains of ilmenite, magnetite, chromite, garnet, etc., seems to be of the same nature as the black sands of the New Zealand coast. Sometimes this black rock shows a banded structure. In the Gobabis district red argillaceous and quartzitic sandstones predominate, and shales only occur in occasional bands. In the Omaruru and Grootfontein districts a group of grey sandstones is succeeded by red sandstones with some beds of conglomerate and breccia. The beds are locally chalcedonised. It seems that the *Fish River Beds* were for the most part laid down in shallow water, but some may be of æolian origin.

As regards the *structure* of the area occupied by the Nama System, the rocks of this system are for the most part horizontal, or dip at a very low angle to the east, as in the western part of Great Namaqualand. But in some areas (Grootfontein, Outjo, and Gobabis districts and the Kaokoveld) they have been thrown into folds.

A great variety of igneous rocks are intrusive in the Lower Nama Beds. Amongst them may be specially mentioned the alkali-rocks in the Luderitz-land littoral, comprising foyaite, bostonite, phonolite, etc. Alkali-rocks also occur in Bastardland.

Many granites of post-Lower Nama age are known, of which may be noted

the Erongo^{31 36} coarse-grained miarolitic biotite-granite, containing tourmaline. The Upper Nama Beds are, on the other hand, remarkably free from igneous intrusions of pre-Karoo age. The porphyries of the Paresis Mountains, however, are intrusive in the Otavi Dolomite and Fish River Sandstone, and include a riebeckite-felsite. A microgranite sill or laccolith at the top of the Otavi dolomite, and aplite stocks which are probably connected with the copper ore-deposits, are found at Tsumeb.

The Karroo System^{16 21 33 37 40 55}.—There is a great gap between the Nama and Karroo systems in South-West Africa, and it is probable that the area formed a land-surface during the interval.

The Karroo System has only been definitely recognised in the southern part⁸³ of this Mandate, though outliers occur as far north as the Gobabis district, and it is probable that certain rocks in the Kaokoveld⁴, known as the Kaoko Formation, belong to this system (see below).

The lower part of the Karroo or *Dwyka Series*³ has been studied in some detail, but of the higher Karroo beds little is as yet known.

As in the Cape Province and Transvaal, terrestrial conditions prevailed, and glacial deposits were formed at the beginning of the period. A typical tillite containing masses of Fish River Sandstone, and resting on a glaciated pavement, is well seen at Nanabis on the Lion River. Beds of conglomerate, calcareous sandstone, and shale are associated with it, and are considered to be of fluvio-glacial origin. A boulder-mudstone composed of boulders dropped by floating ice and imbedded in an argillaceous sandy matrix, occurs at a higher horizon, and passes imperceptibly into shales containing fossils (*Eurydesma globosum* and *Conularia*) similar to those in the equivalent Permo-Carboniferous beds in Australia (*q.v.*) The lamellibranch *Aphanaia* has been recently recognised⁵⁶, and in the Warmbad district⁴² echinoid remains (*Archceocidaris*) have been found in the shales. The thickness and succession of the glacial beds vary, and layers of limestone are occasionally found intercalated, while two tillites are present in some places. The fact that marine fossils are found in the shales, though so far they have not been discovered elsewhere in South Africa, indicates that some at any rate of the beds were deposited in the sea. These *Eurydesma* Shales are succeeded by more shales with thin sandstones, and near the top are thin layers of gypsum. The upper zone of shales and mudstones weathers white, and corresponds with the White Band of the Cape, above which the true *Ecca* Shales commence. Some plant-remains occur in these beds, and in the Ganikobis district the beds have yielded many fish remains, including *Acrolepis lotzi*, *Namaichthys*, etc.³⁵.

The whole *Dwyka Series* in the Keetmanshoop district has a thickness of about 900 ft.

The *Dwyka* Beds east of Gibeon are succeeded by soft grey and reddish micaceous sandstones, with occasional layers of dark shale, at least 560 ft. thick, and similar beds occur in the Gobabis district. These Karroo beds, tentatively referred by Wagner¹ to the *Ecca Series*, have yielded *Glossopteris*, *Cordaites*, and *Catamites*, with petrified wood and small carbonaceous lenticles, but no definite coal seams. They are overlain in the northern and southern portions respectively of the Gibeon and Rehoboth districts, as well as in the Gobabis district by horizontally bedded basaltic lavas with interbedded layers of sedimentary material. The lavas, which are mostly amygdaloidal and are thought to belong to the close of the Karroo period, may be referred to the Stormberg Series.

The beds of the Karroo System are mostly horizontal, except in the neighbourhood of faults, where they are disturbed and tilted.

The igneous rocks intrusive in the Karroo beds are mostly dykes and sills

of dolerite, but some acid rocks occur near Keetmanshoop and in other places. Volcanic pipes, chonoliths, and dykes of kimberlite, similar in character and mode of occurrence to those in the Cape Province, but not yielding diamonds, are known in the Gibeon, Berseba, Bethany, and Maltahohe districts. The peculiar ring-shaped mountain, Geitsi Gubib, is an explosion crater in Fish River Sandstones, and of post-Karoo age, but probably belongs to the same period as the kimberlite pipes.

The Kaoko Formation.—In the Kaokoveld^{4 16 33 40 66} a series of horizontally bedded sandstones and shales, with occasional conglomerates, covered conformably by vast flows of amygdaloidal melaphyre and augite-porphyrity, rest unconformably on the Otavi Dolomite Series, and, as above mentioned, are now proved to be of Karroo age. The fossil plant-remains^{33 35} definitely indicate the age of these beds. Reptilian bones¹⁶ have also been found in the sandstones. A Triassic mammal, *Archceotherium reunigi*⁶⁴, has also been described. The close relations and general correspondence of the Kaoko formation with the Gondwana beds of Brazil are remarkable.⁷² The volcanic rocks⁵³ may be grouped with the Stormberg Series, and probably correspond with the lava-flows of the Drakensberg and the Zambesi which were poured at the close of the Karroo period.

Cretaceous.—A sandy limestone^{49 50} near Bogenfels has yielded a specimen of the Upper Cretaceous ammonite *Placenticas*, with crowds of a species of *Exogyra*. This bed, which lies below the Eocene *Turritella* bed, shows that the Upper Cretaceous sea transgressed the coastal area south of Angola, where beds of this age are better developed.

The series of volcanic rocks, comprising melilite basalts and the phonolites of the Klinghardt Mountains, are ascribed to the Upper Cretaceous or Eocene¹², and point to a period of volcanic activity which it has been suggested may have been contemporaneous with that of melilite pipes near Heidelberg in the Cape Province, and with the Kapitian of East Africa. In the Rehoboth district⁵⁸ there are also trachytes and phonolites occurring as sills or dykes, and in the Luderitz neighbourhood on the coast the foyaites and bostonites may be of Cretaceous or Tertiary age; in the Kaokoveld⁵⁸ there are also volcanic rocks and intrusives of probably the same period. The peculiar granite plugs of the Brandberg^{27 51}, Erongo³⁶, and Great Spitzkop²⁷ are also post-Karoo intrusions. In the Auas Mountains^{78 80} south of Windhoek there is a considerable variety of volcanic rocks⁸⁰ of an alkaline type comprising phonolites⁵⁸, tinguaites, etc., with trachytes forming plugs, which are of post-Karoo, and probably of Cretaceous age. The hot springs⁷⁹ near Windhoek have probably some connection with them.

Tertiary Deposits.—There are scattered patches of Tertiary and Recent marine deposits on the Luderitzland littoral^{6 25} occurring in valleys and depressions; they indicate the former existence of such formations over a much wider area. Sandstones, grits, clays, and shingle (often cemented) are found up to a height of 350 ft., and in the Bogenfels district there are well-defined marine terraces or Raised beaches, one of which lies at a height of 131 ft. and contains marine mollusca, such as *Ostrea digitalina*, *Turritella terebralis*, and *Macra dernburgi*. On the border between South-West Africa and the Union Bbhm¹⁴ has recently determined that the marine beds of the Bogenfels diamond-field which rest on the lavas are of *Middle* and *Upper Eocene* age, as shown by the fossils. There are also *Miocene*¹² beds of marly sandstones in the Bogenfels area which contain mammalian remains^{12 16 19 37 81}, including rhinoceros, antelopes, and hyracoids. It is noteworthy that the species *Myohyrax ostwaldi* Andrews, which occurs amongst them, is also found

in the Miocene of Lake Victoria, East Africa; no proboscideans or primates have been discovered in these Bogenfels beds. Haughton⁴⁵ has described other late Tertiary and Recent deposits on the neighbouring coast. The oldest of them is that containing sharks' teeth and *Kraussina lata*, with other shells, occurring on the Point at a height above present sea-level of about 80 ft. The succeeding deposit is characterised by *Ostrea prismatica*, and varies from 30 to 100 ft. above present sea-level. There are three other zones above it, but the differences in height are due to warping of the terraces and coast line. The various changes in the sea-level along the South-West African coast have led to the formation of these terraces and beaches^{32 60 73}. The Bogenfels terraces vary in height from sea-level to 330 ft., and therefore may be supposed to range in age from Recent to Lower Miocene. The cemented gravels and sandstones contain many pebbles or grains of agate. It is in these terraces and superficial deposits that the diamonds are found^{12 24 38 44 59} (see below).

Superficial Deposits.—It is stated that two-fifths of the country are occupied by superficial deposits, some of which may be of Mesozoic age, for sub-aerial denudation has been going on in South-West Africa since the end of the Karroo period, but no fossils have been found in them to prove their age. The Namib or littoral region is occupied largely by shifting sandstones and coarse detritus derived from the disintegration of the underlying rocks^{32 37}. A crust of surface-limestone is occasionally present, sometimes banded and forming 'onyx marble,' and chalcedonic quartzites, due to the cementation by chalcedony of the grains of sand, also occur. The silicified beds in the Luderitz littoral have been termed by Beetz¹² the *Pomona beds*⁶². Some are of Eocene¹⁴ and others of Cretaceous age^{49 50}, as above mentioned.

In the Kalahari^{10 66 76} region massive sandstones, chalcedonic quartzites, surface-limestones, calcareous grits, sandstones, conglomerates, marls, and calcareous tufa cover wide areas. The surface-limestone is similar to that occurring elsewhere in South Africa. The cementing material in the case of the other rocks may be either of a calcareous or siliceous nature. The Urinani Plateau, 250 miles in length and up to 50 miles in width, is covered by a sheet of this limestone which is largely of fluvial origin. Its thickness varies from 30 ft. to over 300 ft. near the junction of the Molopo and Kuruman Rivers, and it probably underlies the sandveld over nearly all the Southern Kalahari⁶⁶. Beneath the sands, sandstone, and limestone in the south-eastern part of the Kalahari^{10 66} there is a deposit of pink or red calcareous clays, known as the Kalahari marls, and reaching thicknesses of over 50 ft. In places it is split up by a quartzite or silcrete. Red sands spread over immense areas, and are of later eolian origin. Some of these lower deposits may date back to Eocene, or even Cretaceous, times. The fine sand which is spread over the greater part of the Kalahari Desert is probably derived from the disintegration of the underlying arenaceous beds of the Nama and Karroo Systems^{52 66}. These post-Tertiary deposits^{60 73} are intimately connected with the late geological and climatic history of South-West Africa³².

ECONOMIC GEOLOGY

The chief mineral products are *copper* and *diamonds*.

Copper.—The copper-deposits are of various types, but the principal ones occur as lenses in the Otavi Dolomite^{7 13 54 57}, of which those in the Tsumeb Mine are of most importance. The

footwall in this case consists of intrusive aplite, and the ore bodies as well as the aplite are traversed by dykes of much altered olivine-kersantite. The ore itself consists of a massive coarsely crystalline aggregate of argentiferous galena and chalcocite accompanied by other minerals⁵⁷, including chalcopyrite in the lowest level. Metasomatic processes appear to have caused the formation of these ore-bodies.

Magmatic-copper deposits are represented by the coarse-grained copper-bearing pegmatite in the gneiss which occurs on a tributary of the Khan River, near Swakopmund, forming an inclined vein of a variable width up to 7 ft. The copper ore which is most abundant is bornite and is generally accompanied by chalcocite. Other deposits of the same type are known elsewhere in the Mandate. The quartz-veins occurring in porphyry or the gneissose granite carrying copper, and the impregnation deposits in mica-schists are of subordinate importance.

Diamonds.—Diamond-bearing deposits are limited to the coastal region, and in the Luderitz Bay neighbourhood^{5 6 12 24 25 38 44 45 52 59 81} comprise the marine deposits above mentioned, which range in age from Middle Tertiary to Recent times⁴⁵. They occur in valleys or depressions, and consist of sandstone, grit, and cemented or uncemented gravels. But the chief source of the diamonds is the superficial deposits derived from the disintegration of these beds, and usually described simply as 'gravels.' These deposits¹⁴⁵ consist of from 80-90 per cent, of fine sand and the rest is of coarser materials such as rounded and faceted grains of milky quartz, white felspar, yellow chalcedony, banded agate, red garnet, epidote, haematite, magnetite, and specular iron-ore, with occasional fragments of granite and gneiss. In the upper portions of the deposits the finer materials have been blown away by the wind, and a concentration of the coarse detritus has thus resulted⁵². The thickness of the diamond-bearing deposit is usually only 4-6 in., but in some cases amounts to 25-30 ft., with alternating layers of sand and gravel. The diamonds themselves are small and show a great range of colour, and are unlike those found elsewhere in South Africa. It is believed⁴⁴ that they have been derived from the denudation of a primary deposit off the coast, but the nature of the parent rock is unknown, and the absence of any of the well-known constituents of kimberlite in these detrital deposits scarcely allows us to regard the parent rock as having been of this character.

Iron^{61 69}.—Interbedded deposits of very pure iron-ore (haematite and limonite) of immense size and up to 50 metres in thickness are found in the lower part of the Nama System in the western Kaokoveld⁶⁹, **but are not at present worked.**

Tin.—Tin-ore occurs as cassiterite in veins and lenticular bodies of pegmatite⁷⁴ intrusive in the rocks of the Schist Formation of the Fundamental Complex to the north and north-east of Karibib⁷⁴, in the Erongo area³¹, and the intrusions are genetically related to the older granites of the Erongo Mountains³¹.

Tungsten.—Wolfram has been obtained from quartz-veins in gneiss and gneissose granite at Nakeis on the Seeheim-Upington railway.

Vanadium.—This mineral occurs as mottramite (copper-lead-vanadate) at Rietfontein and elsewhere on the surface³⁷, and in cavities in the Dolomite at Tsumeb^{13 54 57}.

Lead and Zinc are found in the Otavi mining area^{13 54}.

Gold^{26 43 77} is found in the Omaruru and Rehoboth areas⁷⁷, and in Ondundu²⁶, where the Damara System is penetrated by quartz veins.

Scheelite, Molybdenite, and other minerals occur in the crystalline schists west of Rehoboth⁴³.

Water.—Water supplies are obtained from wells and boreholes in choked river valleys in the Namib, in zones of decomposed rocks and fissures in the Fundamental Complex, from the Otavi Dolomite in the north, and in the Schwarzkalk and Karroo beds in Great Namaqualand, but the water from the latter source is generally brackish.

There are hot-springs at Windhoek^{39 79} arising from volcanic fissures, probably in connection with the numerous volcanic vents in the neighbourhood⁵¹.

Tectonic Features^{17 29 37 55 63}.—The principal lines of folding in South-West Africa run from north-east to south-west and are post-Archæan⁶⁸ and post-Waterberg, but pre-Karroo. A few lines of faulting and warping of late Cretaceous or Tertiary age have the same general trend. The belt of folds^{17 55} which are parallel to the coast have the same trend as those of the Cedarberg in the Cape Province, and affect the Nama System. The trough-valley in the Namib⁵⁵, and similar valleys to the north of Luderitz, run from E.S.E. to W.N.W. The main trough-faulting in the Kaokoveld⁴⁰ is parallel to the coast and post-Dwyka in age. Block-faulting^{17 55} is much developed in the south in the area between the Orange River and the Luderitz railway. The latest earth-movements occurred in late Tertiary and Recent times, and were of the nature of successive uplifts or depressions, especially noticeable along the coast^{45 60 73}, while in the interior of the country warpings took place.

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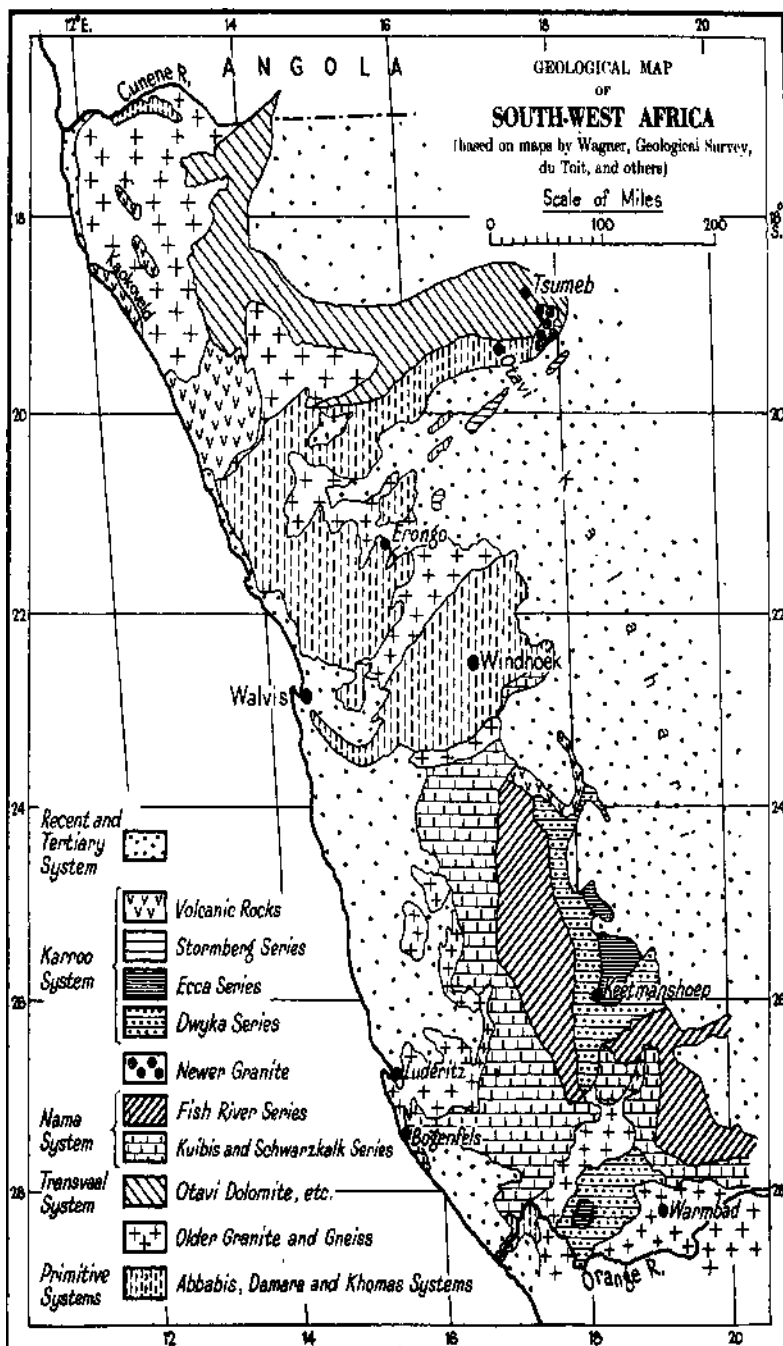


FIG 10

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CHAPTER VI

BRITISH WEST AFRICA

SECTION I.—NIGERIA

General Characters and Geological History.—Nigeria lies mostly on the huge mass of ancient rocks forming the greater part of Africa south of the Sahara, though in places later deposits conceal this common basement formation. It is a remarkable fact that there are no modern fold-mountains in the region or throughout the whole country belonging to the great African Plateau, and none of the rocks of later date than the ancient crystalline foundation has suffered any intense orogenic movements. The only mountains now existing are due either to denudation or faulting, or volcanic activity, and they form either flat-topped sandstone hills, or volcanic plateaus or cones, or rounded granite domes or pinnacles. Another remarkable feature of this region is that from the time of the elevation of this mass of crystalline rocks at the close of the Archæan or Pre-Cambrian to its partial submergence in the latter part of the Cretaceous period, it appears to have been exposed to sub-aerial denudation, and we do not get any of the great fresh-water early Mesozoic deposits such as are so widely spread in South and East Africa. After the Cretaceous marine transgression there was only gentle folding accompanied by faulting which was followed by an Eocene invasion of the sea in the north-west and south-east. Re-elevation took place soon after this episode, and finally there were crustal movements with gentle flexuring and warping of the beds in late Pliocene or Pleistocene times, but there is no evidence of any post-Eocene submergence.

DETAILS OF THE GEOLOGY

Archæan and Pre-Cambrian.—The ancient crystalline basal complex of Archæan and Pre-Cambrian rocks which form the foundation of the whole of Northern Nigeria¹ crops out over extensive areas in the centre of the province, spreading out eastwards from the Niger to beyond Bauchi, and from Nassarawai in the south northwards to the French frontier and beyond it. On the west of the Niger this old platform is again widely uncovered in the districts of Kabba, Ilorin, and Borgu, and passes over into French Dahomey and Southern Nigeria. In the south-east there is another long strip exposed along the southern parts of Muri and Yola, passing over into the Cameroons (*q.v.*).

In Southern Nigeria² the crystalline rocks are most extensively exposed in the north-west districts, and in Ibadan and Abeokuta²⁵ to the west of the

Niger. The southern boundary of these rocks runs eastwards from Abeokuta a little south of 7° N. lat. The hinterland of Lagos consists of the westerly extension of similar rocks, which spread still farther in this direction into Dahomey. An isolated outlier of crystalline rocks constitutes the Oban Hills in the Eastern Province of Southern Nigeria³.

This crystalline complex comprises a great variety of rocks differing largely in age as well as in origin^{4 19-21 25 26 28}.

In Northern Nigeria, where these old rocks occupy about half the surface and have been studied in some detail, Falconer⁵ recognised two series: (1) banded and granitoid gneisses which have suffered re-foliation and recrystallisation during the alteration and metamorphism of the second series; and (2) grits, quartzites (often pebbly), phyllites, schists, and gneisses of sedimentary origin, with some crystalline limestones. Amphibolite and hornblende schists, and other more or less metamorphosed igneous rocks are associated with them. This second series occupies by far the greater area, broad belts of schists, phyllites, and quartzites, highly folded and sheared, occurring in most of the provinces. The two series, which were probably in the first place unconformable, seem to have been folded together along axes which are predominantly meridional in direction, though locally the strike has been twisted transversely; they have also been pierced by numerous igneous intrusions, which are divisible as in the south into an older and a younger group. The older group, which is irregularly distributed over the Protectorate, consists principally of granites wholly or partially foliated, for they have been affected to a varying extent by the forces which produced the metamorphism of the gneisses and schists, and are never sharply marked off from the adjoining gneisses. The members of the younger group are non-foliated, and include granites, aplites, and pegmatites, usually rich in muscovite and tourmaline. The younger, or Plateau granite¹⁹, which is typically a medium-grained biotite-granite varying in texture, occurs as a series of detached stocks, bosses and dyke-like masses separated from each other by more or less extensive areas of the older rocks which it has invaded and which it underlies as a great batholith. There are also felsites and quartz-porphyrries in places at the margins, which are connected in their origin with the younger granite and belong to the same period of intrusion. The syenites and rhyolites of the Shokobo Hills²⁰ are likewise related. In the Kofayi Hills²⁰ three phases of igneous activity can be recognised, an acid phase being followed by an intermediate phase, and this by a basic phase which includes olivine gabbros and basalts. In the Ningi and Burra Hills the earliest intrusion is a quartz-syenite or monzonite; the next comprises a rhyolite-quartz-porphyry series, while the latest is a soda-granite. The younger intrusives are well represented in the Zaria and Kano regions²⁸. The pegmatites in the Nassarawa and Ilorin tin-fields were intruded before the so-called younger¹⁹ granite, and from both of them the tinstone is derived²¹. In the Lake Chad basin the crystalline rocks have been grouped as follows³⁵:—

Younger Granite Series (including rhyolites, quartz-porphyrries, and syenites).

Older Granite Series (chiefly porphyritic granites).

Metamorphic Series (including gneisses, schists, and quartzites).

The metamorphic rocks are the oldest. The chief development of the crystalline rocks in the British area of this basin is in its south-west corner, and joins up with the central plateau of Nigeria. There are also alkaline granites rich in soda, riebeckite- and biotite-granites (with cassiterite and various sulphides occurring in fissures and in the adjoining rocks), syenites, diorites, porphyries, diabases and basalts, the last forming sills and dykes, which are especially conspicuous in Bauchi and Eastern Zaria^{19-21 26 28}.

The 'inselberg' type of landscape, which is characteristic of Africa wherever long-continued denudation has exposed the basement rocks, is developed in these Archaean areas of Southern and Northern Nigeria¹, and is believed to be related to internal structures and differences of composition in the rocks, or to foci of granitic intrusions in connection with successive periods or cycles of erosion.

In Southern Nigeria the oldest rocks, according to Kitson^{7 12}, comprise a series of altered sedimentaries and igneous rocks, including schists, quartzites, marbles, limestones, altered lavas and tuffs, amphibolites, and gneisses. Their strike varies from west-north-west and east-south-east to north-east and south-west, and they are found in the north-western portion of the country (Yorubaland) north of lat. 7° N. and in the Oban Hills region in the east. Intruded into them are large masses of granite, etc., which have occasionally shared in the dynamic alteration which the older series has suffered. In the Oban Hills³ there are likewise two groups recognisable amongst these old pre-Cambrian rocks; one group is characterised by foliation, and the other by the lack of this structure. The foliated group consists in part of acid orthogneisses, passing by the loss of foliation into granites¹⁴. The commonest rock of the series is a fine-grained biotite-gneiss. Mica-schists and, less frequently, hornblende-schists (with some sphene-schists and sillimanite-gneisses) also occur, and are believed by Parkinson to be older than the gneisses. These foliated rocks contain monazite. Phyllites and grits changed into spotted slates and schists have also been described near the Calabar River. The unfoliated group consists of many varieties of granite, aplite-dykes, and pegmatites bearing tourmaline. Probably this group corresponds to Falconer's younger group of intrusives in the north. But the olivine-basalt dykes, which are found in the Oban Hills, are regarded by Parkinson as of post-Cretaceous age. To the east and north-east of Abeokuta Wilson²⁵ describes the succession of rocks which is essentially the same as that in the Northern Province. The oldest rocks of the crystalline series are here of sedimentary origin (quartzites, quartz-schists, mica-schists, gneisses, etc.), and they have been invaded and largely replaced by a succession of igneous rocks comprising granitic and banded gneisses of many kinds, talc-rocks, etc., with pegmatites. All have been markedly foliated, and the meridional strike of the foliation is usually constant, though locally it may vary. An older and a younger intrusive group of rocks in this series have also been recognised here. The older comprises hornblende-epidote-schists, anthophyllites, and talc-rocks, all of which occur as dykes. The younger group consists of various types of banded biotite and hornblende gneisses, epidiorite and pegmatite dykes. A still later unfoliated set of intrusions includes dykes of basalt, dolerite, and ultrabasic rocks, the age of which is not known.

Trias P—An isolated occurrence of limestone in Northern Nigeria, near Gomba and Giro, close to the junction of the Sokoto and Niger rivers, has been attributed to the Muschelkalk on the strength of certain fossils. But the evidence seems doubtful, and has not been confirmed, and no other occurrence of such rocks has been recorded⁶, and it appears that there is a break in the succession of strata till the Upper Cretaceous, no intermediate deposits being at present known.

Cretaceous.—The earliest sedimentary beds with indisputable fossil evidence recognised in any part of the whole region belong to the Upper Cretaceous period", and these are fairly extensively developed both in Northern and Southern Nigeria. They possess two distinctive facies, one marine and the other fresh-water or estuarine.

In NORTHERN NIGERIA the upper part of the system is represented by beds

approximately equivalent to the Cenomanian and Turonian of Europe⁴, and is developed in the valleys of the Benue and Gongola rivers. These beds are usually gently folded into synclines and anticlines, but sometimes the folding is more intense, and faults are also developed. Three divisions of the Cretaceous beds have been recognised :—

3. Upper Grits and Sandstones.
2. Limestones (Turonian).
1. Lower Grits and Sandstones.

The Lower grits and sandstones are well developed in the provinces of Muri and Yola, and include calcareous shales and marls in the upper part of the series. The sandstones are sometimes red and sometimes grey, and in Muri are frequently saliferous, weak brine springs arising from them. These beds form the lower hills, but are chiefly spread over the plains of Muri and Yola. Their thickness is estimated at over 1000-1500 ft. (The so-called Bima Sandstones of Bauchi and Bornu, which also occur in the southern part of the Chad basin³⁵, may belong to the same set of beds.)

The Lower grits and sandstones pass up gradually into the Turonian limestones, which are often shaly, and are only a few hundred feet thick. They yield many fossils, which include ammonites belonging to the genera : *Vasocerat*, *Mammites* (*Pseudaspidoceras*), and *Hoplitoides*, and some gastropods and lamellibranchs, including *Pecten* (*Neithea*) *quinquecostatus* Sow., *Ostrea prelonga* Sharpe, and *O. (Exogyra) olisiponensis* Sharpe, the latter species also occurring in the Cenomanian of northern Africa. The whole fauna is stated¹ to be closely allied to that found in beds of similar age in Portugal, Tunis, and Algeria.

The Upper grits and sandstones are well developed in the provinces of Bauchi and Bornu, and consist of red, white, and yellow sandstones, grits, clays, and ironstones, containing silicified wood, and rest upon the Turonian limestones. Their total thickness is at least 800 ft. These rocks may correspond with part of the Nubian Series of the Sudan.

In the *Sohoto* province³⁰ there is a series of beds consisting of sandstones, calcareous muds, and limestones, known as the *Rima Series*, of which the lower part has yielded the reptile *Mosasaurus*³⁰ and fish-remains³¹, and is referred to the Upper Cretaceous, but the rest belongs to the Eocene.

In SOUTHERN NIGERIA² the Cretaceous⁷ is a variable series of marine and estuarine fossiliferous shales, mudstones, limestones, sandstones, and grits, the coarse sandstones forming conspicuous ridges in the south-east parts. These beds flank the Oban Hills, and extend northwards into Northern Nigeria and westwards under the Udi-Okwoga highlands, where they pass into freshwater beds containing valuable coal seams^{8 23 24 29} of sub-bituminous coal (Udi coal-field). On the Eastern Railway between Port Harcourt and Enugu^{23 24} the Cretaceous Series consists of a lower Shale group, a middle Coal Measure group, and an upper Sandstone group. In the Shale group fossils are scarce, but a few lamellibranchs have been recorded; from the Lower Shales the ammonites²⁹ indicate an Albian age, but the Upper Shales have yielded *Cardita beaumonti*²³, which points to the Maestrichtian. The coal measures and sandstones have yielded no fossils from which a definite determination of their age can be made. To the west of the Cross River, and in the great valley between the Oban Hills and the Udi Plateau, fossiliferous marine shale³, etc., occur, containing ammonites of the genus *Hoplitoides* and the lamellibranchs *Protocardia hillana*, and species of *Lima*, *Ostrea* and *Exogyra*. In the Abakalliki district marine Cretaceous strata carry lodes of silver, lead, zinc, and iron ore, formed along fault lines. There is stated to be a passage up into the Eocene² in Southern Nigeria, the marine Cretaceous **gulf** having

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been apparently gradually silted up and estuarine and lacustrine beds deposited in it. But in Northern Nigeria earth-movements took place at the conclusion of the Cretaceous, resulting in an unconformity below the Eocene.

Tertiary.—The beginning of the Eocene in Northern Nigeria was marked by the folding and faulting of the Cretaceous beds during these movements, and this was followed by intense erosion and then depression. During this submergence sandstones, clays, limestones, and ironstones attributed to the Middle Eocene were deposited on the worn edges of the Mesozoic beds.

In the north marine conditions prevailed, but as we trace the beds southwards from Sokoto the marine beds die out and estuarine or lacustrine shallow-water beds increase in volume till at Lokoja they are 1000 ft. thick, and we enter into the region where there is no break apparently between the Cretaceous and Eocene.

In the *Sokoto region* in north-west Nigeria⁸⁰ there is a series of calcareous marls, gypseous shales, chalky and nummulitic limestones with ferruginous grit, oolitic ironstone and sandstone at the top, in all 1000 ft. thick. These beds comprise the Middle and Upper groups of the *Rima Series*. They form isolated hills and plateaus, 300-400 ft. high. From these beds Middle Eocene fossils have been obtained belonging to the genera *Nautilus*, *Turritellu*, *Voluta*, *Calyptrea*, *Lucina* (*L. thebaica*) *Spondylus*, *Hemiasper*, *Linthia*, *Plesiolampas*, etc.—a fauna showing Egyptian and Indian affinities^{9-11 27 30 31}. This fossiliferous Eocene portion^{30a} of the series has a thickness of about 70 ft.

The *Rima Series* in the Sokoto province is succeeded (probably unconformably) by at least 400 ft. of unfossiliferous clays, sandstones, and conglomerates, of uncertain age; these are followed by another group of sandstones, sands, tough clays, basal conglomerates, and arkoses, of unknown thickness and also unfossiliferous^{30a}.

On the south and south-east flanks of the Udi Plateau in *Southern Nigeria*, and extending over the southern part of the great valley of the Cross River, Kitson¹² describes a series of Eocene estuarine shales, clays, and marls, with septarian nodules and pieces of coal and resin, and a rich fauna consisting chiefly of mollusca, but including fragmentary remains of whales, birds¹⁵, fishes²⁷, and turtles. There is a total absence of *Nummulites* in the collection from Ameke, but some corals, echinoids⁵, and Crustacea¹⁷ are known, and the mollusca¹⁸ include many gastropods and species of *Clineoropsis*, *Plicatula*, *Glycimeris*, etc., and point to a Middle Eocene age for the beds, with special relations to the Mokattam of Egypt, the Claiborne of America, and the Middle Eocene of Europe¹⁸. These beds^{17 18}, which occur between Port Harcourt and Enuga, are termed by Wilson²⁴ the *Bende-Ameke Group* and are correlated with the Upper Lutetian. They are succeeded by the Lignite Group (see below). In the Onitsha and Owerri areas in the Nigerian coalfield region there is a formation termed the *Carbonaceous and Pebbly Sandstone Group*²⁹ which is earlier than the Bende-Ameke beds, but subsequent to the uplift, folding, faulting, and denudation of the Cretaceous, there being a strong unconformity between it and the Coal Measures. It is probably of Lower Eocene age. At its base there is in one place, at the foot of an escarpment, a sandstone impregnated with bitumen and with a seepage of oil²⁹.

In the Niger Valley below Jebba, and in southern Kontagora, there are no marine beds or limestones, but grits and ferruginous sandstones, conglomerates, and ironstones to a thickness of 1000 ft. which represent shallow water- and lacustrine conditions. These have been termed the *Lokoja Series*, and are believed to be continuous southwards with the fresh-water beds of supposed Eocene age in Southern Nigeria known as the *Lignite Series**. They consist of a thick series of sandstones, clays, and shales, containing layers of lignite

and brown coal, with undetermined plant-remains, chiefly dicotyledonous, and ore well developed in the Central Province of Southern Nigeria. No well-preserved or distinctive fossils have so far been found in them. The Lignite Series is typically developed on the west bank of the Niger, and forms a large portion of its basin west of the Udi Plateau. In the Asaba district the lignites are of considerable economic importance, some seams being 12-23 ft. thick²⁵.

The only true marine bed of Eocene or Miocene (?) age which is known in the south or near the coast, is an Orbitoidal limestone crowded with *Ortho-phragmina*¹¹; it occurs in the Lagos Province, and a short distance west of the apex of the Niger Delta.

In eastern Bauchi and Bornu in Northern Nigeria there are grits, sandstones, and clays of post-Cretaceous age, everywhere unfossiliferous, but presenting many analogies to the Eocene rocks of the Niger Valley, on the strength of which they are believed to be of Eocene age¹. The beds are horizontal, and have a considerable thickness, amounting in places to about 1000 ft. In the south-west part of the Lake Chad basin³⁵ the supposed Eocene rocks are known as the *Kerri-Kerri Group* and resemble certain beds in the Sokoto Province which directly overlies limestones and shales of Maestrichtian-Danian age. The Kerri-Kerri beds consist of sandstones, grits, and clays which are unfossiliferous except for indeterminate plant-remains and lie nearly horizontally and unconformably on the inclined Cretaceous beds.

The Benue plain in the Yola Province is also occupied by a thick series of sandstones, grits, and arkoses, often massive, which form flat-topped hills, and rest horizontally on the Cretaceous limestone and shale series or directly on the crystalline rocks. These beds, which are believed to be of Eocene age and are known as ' *Upper Benue Sandstones 1*, pass over into the Cameroons, where also marine fossiliferous Eocene deposits occur. In the Abeokuta Province²² phosphate deposits of Eocene age occur containing minute molluscan casts, fragments of echinoids, and remains of an English genus of Eocene snakes (*Palæophis*). The beds are several feet thick in places and occur in association with clays and grits, indicating marine incursions during lagoon conditions.

Pliocene or Post-Pliocene.—In the Ijebu district (Lagos Province)⁸, and generally in the southern parts of the Western and Central provinces of Southern Nigeria, there is a variable series of clays and sands often impregnated with bituminous substance. This series is known as the *Ijebu Series*, and has yielded species of *Area*, *Cardium*, *Cuspidaria*, *Barnea*, and *Dentalium*, which indicate a Pliocene or post-Pliocene age¹¹. It is on this horizon that the petroleum of the district occurs.

Post-Tertiary and Superficial Deposits.—In Southern Nigeria an extensive sandstone or clayey formation, known as the *Benin Sands*²⁴, covers wide areas, and extends up the Niger at least as far as Asaba, and across the river to Benin City and beyond, occupying practically the whole of the country south of lat. 7° 10' N., and west of the great valley of the marine Cretaceous. These sands, which are believed to rest unconformably on the Ijebu beds, vary much in character, thickness, and composition. They comprise red, brown, or yellow sands, sometimes compacted into sandstones 150 ft. thick, mottled sandy clays, pebble-beds, and fine quartz-conglomerates, and are typically found⁸ in the Central Province and Calabar district. There is a definite unconformity²⁹ between these sands and the Lignite group. Their thickness varies, but in one place it reaches 600 ft.²⁹, though their total thickness is uncertain, and they are usually unstratified.

In Northern Nigeria there are no fossiliferous deposits known of later date

than the Eocene, but the plains of northern Bornu, Katagum and north-eastern Kano are underlain by a group of post-Eocene deposits known as the *Chad Group*³⁵, and consisting of felspathic sands and gravels and thick greenish clay with thinner sandy bands intercalated. Considerable deposits of diatomite occur also in places. The whole Chad Group is spread over 35,000 sq. miles in Nigeria and is covered by surface accumulations. It extends over a still larger area in the adjoining French territory, where the Cretaceous and Tertiary beds³⁷ have been extensively studied and their southward extension traced. Red sandy loam with calcareous concretions (*hunhar*), surface-ironstones composed of quartz-grains and pebbles in a ferruginous cement, white and yellow æolian sands, valley alluvium, and laterite, are the principal types of the surface deposits. The present tin-bearing alluvium, which is found over extensive areas in Bauchi and elsewhere, is composed of the products of disintegration of the solid crystalline rocks and the surface-ironstones, etc.

In Southern Nigeria, along the coast-line, and extending for considerable distances up the Niger and Cross rivers, are fluviatile, deltaic, littoral, and swamp gravels, sands, and muds of Pleistocene or Recent age¹².

Tertiary volcanic rocks attain a considerable importance in Northern Nigeria. Two separate periods of volcanic activity have been recognised, one in Middle Eocene times, and the other in late Pliocene or early Pleistocene times. The Middle Eocene eruptions were mostly of an isolated character, and gave rise to the formation of detached pipes, cones, and puys, and more rarely (as in southern Bornu and the borders of Bauchi and Nassarawa) of continuous sheets of lava. Stumps of phonolite, basalt, and trachyte belonging to this group occur from the Gongola Valley westwards to northern Muri. In Northern Nigeria on the Bauchi Plateau and to the south of it the superficial gritty deposits and clays have been found to be of volcanic origin and to represent thoroughly decomposed basaltic lavas. These deposits are known as the *Fluvio-marine Series*^{19 26} and seem to belong to an earlier period of vulcanicity than that of the Sura Hills²⁶ (see below). On the southern part of the plateau fresh and undecomposed lava-flows are associated, and comprise olivine-bearing and olivine-free basalts which are practically indistinguishable from those associated with the most recent volcanic foci. Flat-topped outliers of basaltic lavas occur in places, and the fluvio-volcanic hills are capped with lateritic ironstone.

The Pliocene or later eruptions consist of puys on the southern margin of the Bauchi Plateau, in northern Yola, and probably include those in the middle Benue region. They are represented by perfect craters and ash-cones with associated lava-flows, all of basalt rich in olivine passing into limburgite^{19 21 26}. In the Sura district of the Bauchi Province²⁶ there is a series of recent very perfect volcanic cones and craters along a north and south line. The lavas are vesicular basalts, and the craters are mostly breached by the outflow of lava streams. Recent large flows of basalt are spread out also on the Kaura Hills²¹ and north into Zaria and Kano²⁸, where some extensive sheets of basalt up to 50 ft. in thickness cover large areas²⁸. Near Zaria in the Kudu Hills the younger intrusive rocks consist of a great variety of petrological types which have been described by Bain³⁴.

Late Earth-Movements.—With regard to Tertiary earth-movements, Falconer is of the opinion that Northern Nigeria suffered elevation in late Pliocene or early Pleistocene times accompanied by gentle folding. The axes of these folds run in two directions, approximately W.S.W. to E.N.E. and N.N.W. to S.S.E., and the

influence of these two axes of elevation has led to important recent hydrographical changes.

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Gold.—In Northern Nigeria³³ gold occurs in river deposits and river terraces, in saddle-reefs, in the schists of the Basal Complex north of Minna, and in banket-conglomerate beds at the base of the Eocene ('Nupe Sandstone Series') which forms broad bands of sandstones, grits, and conglomerates in the extreme south-west and north-west of the Province along the banks of the River Niger. In the country east of Minna there is a wide tract of gneissose granite with patches of metamorphosed sediments on which lie superficial deposits which are largely auriferous³².

Tin.—The most important mineral deposits of Nigeria are those of tin, and they chiefly occur in the Bauchi Province¹⁹⁻²¹. It is principally the alluvial or residual gravels which are worked, but the original stanniferous granite and pegmatite have been discovered in some places. The tin occurs as cassiterite, and seems to be genetically connected with the later series of intrusive granites and pegmatites, which are partly of an alkaline nature and are not foliated^{19-21 26 28}. It is found in veins or as impregnations in these rocks. The tinstone in the case of the tinfields of the plateau¹⁹ and Northern Bauchi²⁰ has originated in connection with the younger granite and other intrusions^{20 28 34}, being mainly due to pneumatolytic action on the granite and gneisses near their contact, which has given rise to gneisses usually containing topaz and tin and carrying networks of quartz veins with tinstone. In the case of the pegmatite dykes of Nassarawa²¹ the tinstone is an original constituent which had commenced to crystallise before the intrusion of the rock²¹. Tourmaline is nearly always present in these pegmatites, though it is absent from the younger granite, with which the pegmatites seem to have no connection. The tinfields of Zaria and Kano²⁰ are likewise in an area of older crystalline rocks, gneisses, schists, and granites with pegmatite dykes.

Wolfram³⁶.—This mineral occurs in quartz-veins and lodes in the younger granites and also in detrital deposits.

Coal.—The Cretaceous coal of the Udi (Enugu area) coalfield²³ on the east side of the River Niger is sub-bituminous and non-coking. There are five persistent coal seams in this area, all apparently of Cretaceous age, with varying thicknesses. In the Onitscha and Owerri areas²⁹ the beds are much more disturbed; the coal seams here range from 1½ to 2½ ft. in thickness.

Phosphates²².—The phosphatic deposits of Eocene age in the Abeokuta Province²² occur on three horizons. The first consists of a sheet of bedded phosphate of the granular and nodular types, and reaches 4 ft. in thickness. The second is characterised by blocks of phosphatised limestone embedded in clay, and the third, about 50 ft. below the first, is a bed of fine vesicular type of phosphate rock.

Lead.—Argentiferous galena occurs in veins in the Cretaceous rocks of western Muri, and numerous silver-lead-zinc-iron lodes occur along fault-lines in Southern Nigeria.

Monazite.—Monazite is widely distributed in the tin-bearing gravels of Northern Nigeria.

Salt.—Salt is produced from the evaporation of the water of brine-springs and pools in the province of Muri; it is believed that it comes from the 'Muri Sandstones' of Cretaceous age which lie below the shales and Turonian limestones. The springs seem to be specially associated with the anticlinal axes of the folds into which the beds have been thrown.

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SECTION II.—THE GOLD COAST AND ASHANTI

The Gold Coast Colony covers about 24,000 sq. miles, and the Ashanti and Northern Territories Protectorates about another 55,000 sq. miles. Geologically the country consists mainly of crystalline and metamorphic rocks of various types, or of unfossiliferous sedimentary rocks of probably pre-Palæozoic age, and these are of the same general type which is widely distributed throughout West Africa south of the Niger⁹ 11. Amongst the Archaean and Pre-Cambrian rocks⁴ is a series of highly or moderately metamorphosed sediments including mica-schists, quartz-schists, quartzites, phyllites, slates, limestones, sandstones, grits, breccias, and conglomerates. These occupy the middle and western parts of the Gold Coast Colony and Ashanti, and occur on the western side of the Northern Territories. From the coast they extend inland, generally in a north-easterly direction, from the east of Accra to the north of the Ankobra River west of Axim, striking from south-west to north-east. Usually they are only widely folded, but locally they have suffered intense plication and contortion along numerous well-defined zones parallel to their strike. Four formations or systems have been distinguished, all of which are separated by great unconformities. The oldest, termed the *Birim*¹⁰ (*Birimian*) System, is composed of phyllites, schists, gneisses, etc. The next younger formation is known as the *Tarkwa* (*Tarkwaian*) System⁹ 11 16, and consists of quartzites, phyllites, sandstones, and banket-conglomerates, in all over 6000 ft. thick.

In the eastern part of the colony near the coast in the Krobo and Shai Plains, and extending back from the coast near Accra, is a great mass of gneisses, amphibolites, sheared pegmatites, etc., having the same general strike as the altered sediments, but their precise relations to them have not been determined. Biotite- and hornblende-gneisses seem to be the chief types of rock which are here developed¹ 5 6. Some of these rocks may be older even than the *Birim*¹¹ 15, or may be only metamorphosed portions of that system. From the central Sahara down to south Dahomey and through the Gold Coast, Togoland, and Ashanti, these old basement rocks have a sub-meridional strike, and seem to form series of long rectilinear ranges of pre-Upper Silurian or possibly greater age. They have been compared with the rocks of the Caledonian System of folds in Europe, and have received the name of the Saharides.

Through these rocks have been intruded, at various stages, numerous masses of granite, diorite, porphyry, pegmatite, and other igneous rocks, which in some cases have shared in the dynamic

changes. Dyke-rocks, chiefly dolerites and diabases, are also abundant.

A third unfossiliferous system in the Akwapim Range north of Accra has been called the *Akwapim (Akwapimian) System*¹¹. The rocks consist of red and yellow phyllites, fine mica-schists, pebbly grits, haematite-sandstones, quartzite, etc., in some places much folded, but in others flat-bedded. In one place it rests on the decayed surface of the biotite-granite which is intrusive into the Birrim System. The general character of the Akwapim System is said to resemble the Black Reef Series of the Transvaal. The fourth, or *Volta (Voltaian) System*³, has a much wider distribution than the Akwapim, and occurs over large portions of the Volta River basin and on certain plateaus and extends east and west into Togo and Dahomey³⁵. It consists of sandstones, quartzites, and conglomerates, resting on the Birrim and metamorphic rocks; it reaches 1000 ft. in thickness. The beds are more generally flat-bedded and horizontal, and from their water-bearing capacity give rise to numerous streams. All are unfossiliferous. It is in the gold-fields that the whole succession has been most thoroughly worked out 16 17 18.

Devonian.—The earliest fossiliferous rocks discovered on the Gold Coast occur in a small faulted mass of quartz-grits, sandstones, clay-shales, and mudstones near Accra, containing Lower or Middle Devonian trilobites (*Homalonotus dekayi* Green) and mollusca belonging to the genera *Nuculites*, *Palceoneilo*, *Glyptodesma*, etc., with *Hyolithes* and *Lingula*. This has been termed the *Accraian System*^{10 11}.

Carboniferous.—One mile north of Sekondi¹¹ and eastward along the coast there are sandstones and clay-shales with calcareous nodules containing casts of lamellibranchs (*Posidonomya becheri*) with *Orbicvloidea nitida* Phill., which are referred to the Lower Carboniferous, while at Takoradi south-west of Sekondi fragmentary remains of fish, *Pleuracanthus* and palseoniscids, have been found, with fragments of plants which are regarded as of Upper Carboniferous age¹¹. These Carboniferous beds have been called the *Sekondian System*.

Cretaceous¹¹.—In western Apollonia in the Beyin district bluish-grey mudstones, lenticular yellow fossiliferous limestones yielding broken and indeterminable lamellibranchs, foraminifera (*Cristellaria*, *Globigerina*), and one ammonite (possibly belonging to the genus *Puzosia (Pachydesmoceras)* and comparable with the species *denisoniana*, which occurs in the Cenomanian of the Cameroons) are exposed along the coast and inland for some distance in western Apollonia. Heavy oil occurs in the upper portion of these deposits.

From the region in which these beds occur the name *Apollonian System*¹¹ has been applied to them.

Pleistocene P—On the coast between Saltpond¹¹ and the Amisa and Nakwa rivers there are clayey and pebbly deposits, with silts, grits, and gravels; in the silts there are in places large boulders of quartzite and slabs of slate, while at Sekondi quartz-pebbly gravels lie on the Carboniferous beds. To these supposed Pleistocene coastal deposits the name *Amisian System* has been given by Kitson¹¹.

Some marine terrace-gravels may be of Pleistocene age, and on the coast three raised terraces have been found, the uppermost one being 70-100 ft. above sea-level. Representatives of the Benin Sands of Nigeria also seem to occur.

Igneous Rocks.—The petrological characters of some of the typical igneous rocks of the Gold Coast have been described by Junner²⁰. Of these the oldest is a biotite-granite with associated biotite-pegmatite, intruded into the Birrimian System. The next is a muscovite-granite, also intruded into that system but not into the Tarkwaian; dykes of pegmatite and aplite with veins of quartz containing gold, cassiterite, molybdenite, wolfram, etc., are connected with them. The next is a group of red granite and porphyries of various kinds and has a wide distribution. Ultrabasic rocks occur chiefly as large and small dykes. There are great masses (sheets) of dolerite interbedded with the Birrimian System, and necks and dykes of this rock pierce the early Voltaian or late Akwapimian rocks. Other igneous rocks are somewhat rare. Similar metamorphic and igneous, as well as sedimentary unfossiliferous rocks, are developed in the adjacent French Ivory Coast, and have been described by De la Rue²⁸.

Recent Volcanic Rocks.—The remarkable circular Lake Bosumtwi^{23 81 82} in the interior of Ashanti occupies the hollow of an explosion-crater. The crater-like walls rise 300 to 600 ft. above the surrounding country and enclose an area 6½ miles in diameter. The rocks through which it has burst are phyllites with a N.N.E.-S.S.W. strike; a broad granite dyke traverses them and the middle of the lake. The presence of dacite-tuffs³¹ around it indicates that the hollow is of volcanic origin and not due to the fall of a meteorite. The Nebievale³⁷ caldera in the Northern Territories is believed to be due to two sets of faults crossing each other and dropping down the enclosed block.

ECONOMIC GEOLOGY

Gold 7 9 11 13-18 26. _Gold, which is the chief mineral so far worked, occurs in the older conglomerates (Tarkwa and Wassau).

In the Tarkwa gold-field the older rocks were first divided^{2 3 16 25} into a lower Banket Formation and an upper Clay-Slate Formation. The Banket Formation³⁴ consists of sandstones and quartzites with inter-bedded auriferous conglomerates and some dolomite. But this early classification and nomenclature is now superseded, and the beds in the Tarkwa-Abosso gold-field^{16 26} are now assigned to the Birrim and Tarkwa Systems^{16 26}. The Birrim System here consists of indurated and folded sedimentary and volcanic rocks of various kinds. The sediments vary from black manganeseiferous and graphitic schists through blue-banded and grey to mauve, pink and yellow phyllites. Associated with the black and blue sediments are the Insuta-Dagwin deposits of high-grade manganese ore³⁶. Overlying them unconformably is the *Tarkwa (Tarkwaian) System*, consisting of a basal conglomerate (the Kawere conglomerate) and the Banket⁸⁴ group, in all 2100 ft. thick, and this is succeeded by sandstones, phyllites, and quartzites, in all about 3000 ft. thick. The conglomerate is argillaceous with rounded pebbles of quartzites and volcanic rocks. The system has the prevalent north-east to south-west strike, and dips north-west at from 30° to 60°. It has been correlated with the Witwatersrand System of South Africa, and the field has a noticeable petrological and structural resemblance to that of the Rand. The auriferous conglomerate varies from 6 to 20 ft. in thickness. In the Obuasi Gold-field¹⁷, in which the Ashanti Mine ' is situated, we find the same general succession, the Birrimian System being represented by the so-called Obuasi Series, which consists chiefly of grey and black slates, phyllites, and sericitic schists. Volcanic rocks are most developed near the top of the series. The Tarkwaian System follows, but there is no marked discordance between the two formations, though the pebbles in the Kawere conglomerate are very largely derived from the Birrimian rocks. Quartzites, grits, and phyllites follow. Intrusive granitic rocks, and olivine-norite, gabbro, epidiorite and dykes of dolerite occur in the field. The ore-bodies are found in persistent deep-seated shear-zones; the main quartz-reefs are lenticular in shape and occur in the Birrimian phyllites and schists. The gold in them is usually finely divided and rarely visible. The conglomerates, said to be four in number, are stated to differ in no way from those of the South African Rand, except that they, as well as the associated sandstones, contain much haematite and ilmenite instead of pyrites in thin veins or in the matrix, and that the pebbles themselves, as well as the matrix, contain gold⁷. The pebbles, which range up to 8 in. in size, are of a full white quartz, and are embedded in a micaceous sandy matrix. The whole formation is estimated at from 4000 to 8000 ft. thick. The beds in the Tarkwa²⁶ field are thrown into gentle folds, the series of anticlines

and synclines having their axes trending from north-east to south-west ; they are also traversed by faults striking east and west, and by dykes and sheets of dolerite, diabase, etc.

Auriferous quartz-veins are of much importance in the older rocks, as at Obuasi¹⁷, Ashanti, as above described. Auriferous localities are also known in the Northern Territories. The quartz -veins are generally in parallel zones of Assuring in graphitic schists, traversed by intrusive dykes, but the gold in some cases forms impregnated zones in micaceous schists. In the Marlu area the overfolded schists contain auriferous zones^{21 22}. Much alluvial gold occurs also in river deposits.

Diamonds^{19 25 29} have been discovered in quartz-gravel at Abomoso, north-west of Kibbi, Eastern Province, Gold Coast, and elsewhere^{9 19 25}. The bed-rock is in some cases decomposed grey-wackes and phyllites, and in others is decomposed volcanic rocks or tuffs, all belonging to the Birrim Series, which seems to be the original source²⁵ of the diamonds. The gravels²⁵ appear to be all of Pleistocene to Recent age and contain in places Neolithic and Middle Palaeolithic implements as well as in one place a layer of carbonised plant-remains, all of which belong to the present-day flora. But the high-level lateritised gravels on the hill tops may be older and are mostly barren or contain few diamonds. The occurrence of typical Gold Coast diamonds in the Tarkwaian banket at the Ashanti-Adowsena Mine and the close geological association of alluvial diamonds with the Kawere conglomerate at the base of the Tarkwaian in the Bonsa field^{11 28} and elsewhere in certain places 'strongly suggest that the diamonds were derived from Birrimian rocks.' In some respects the Gold Coast diamonds are similar to those from Brazil. There is no evidence of the presence of volcanic plugs or kimberlite.

Manganese.—Manganese^{9 16 24 27 36} is found in large quantities in the Tarkwa district (Dagwin Concessions) in the Birrim System.

Iron Ores.—Iron ores⁹ are widely distributed, chiefly as impure limonite, and some of the surface-deposits are of good quality, varying in thickness up to 20 ft.

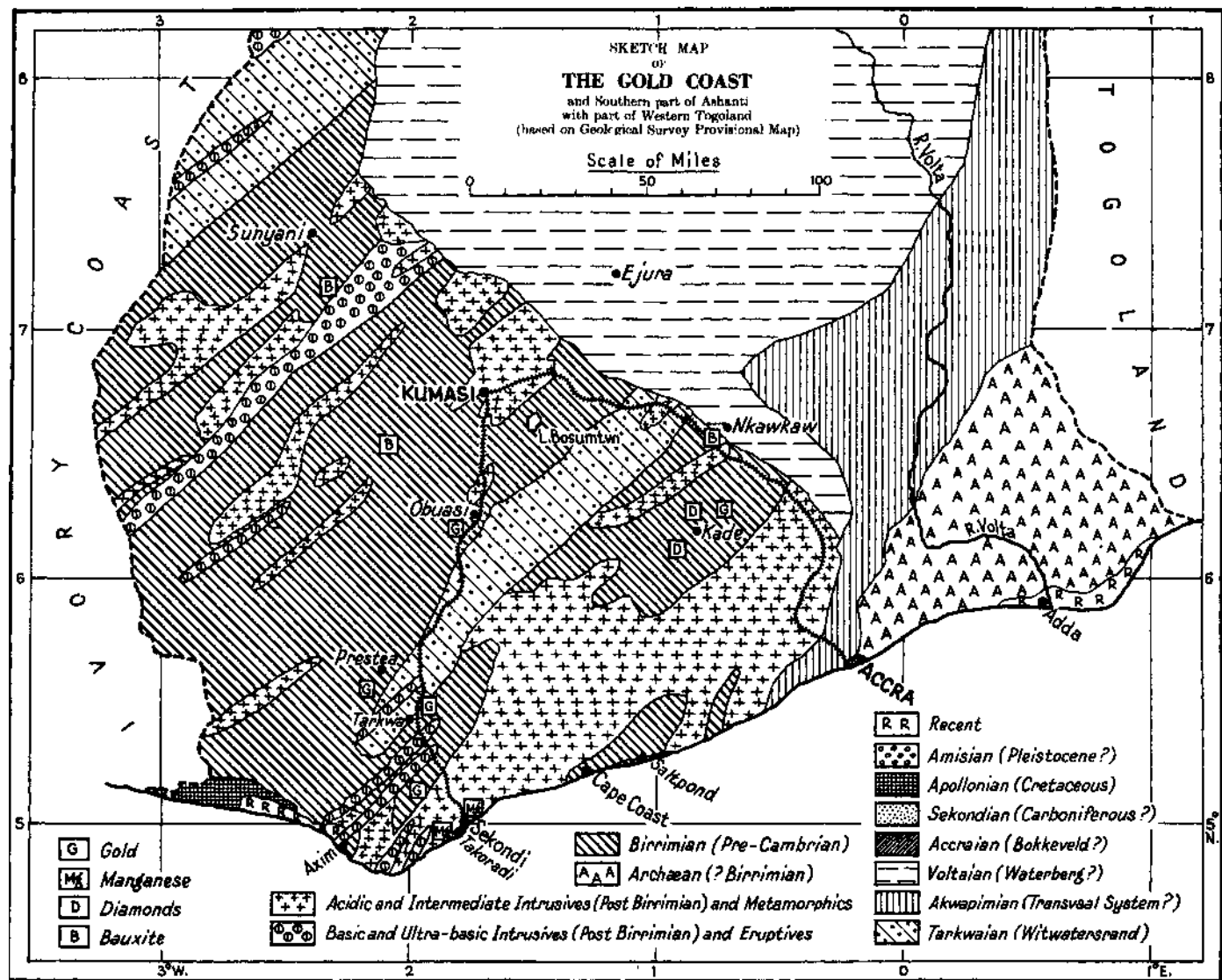
Bauxite^{8 9 12 30 33}.—Bauxite is found in large quantities on the Kwahu Plateau on Mount Ejuanema and on Mount Supirri. It is derived from the steeply-dipping phyllites, lavas, and tuffs of the Birrimian Series, and from the nearly flat-bedded shales of the Voltaian³³.

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SECTION III.—SIERRA LEONE

The Colony consists of a mountainous peninsula and of a low-lying coastal plain, with the Protectorate inland, which is an upland region composed of a series of broken plateaus^{6 7}. The peninsula consists of a great noritic complex^{3 4 8} with hortonolite-dunite dykes resembling the Bushveld Complex in the Transvaal. The coastal plain consists of gneisses and schists^{1 2 7}. These belong to the Basement of ancient crystalline rocks which is spread over wide areas in the Protectorate and which Dixey calls the '*older schists and gneisses*,' comprising amphibolites and hornblende-schists, talc-schists, quartz-magnetite-schists, tourmaline-schists, and charnockite rocks; these rocks have been intruded by granites and granite-gneisses and are widely spread over the Protectorate. Nearly all the granites are of the alkaline (potassic) type. The older gneisses occur as included masses in the later granites which themselves show gneissic banding and foliation of varying direction. Minor intrusions of granophyric rocks, syenites, quartz-diorites, gabbros, etc., occur among the granites. Junner¹² recognises an older series of schists as the *Kambui Schists* which are intruded by the muscovite-granite, but are older than the biotite-granite. This formation includes quartzites and banded ironstones as well as quartz-schists. A newer series of schists, which he calls the *Marampa Schists*, consists of argillaceous phyllites, sericite schists, and subordinate quartz-schists; these are important economically for they contain the rich haematite deposits¹⁷. Of later date than any of the above-mentioned rocks, since they rest unconformably on the granites, are the beds composing Dixey's *Rokell River Series*, the lower division of which consists of a basal conglomerate overlain by felspathic sandstones; this is followed by an upper division (which in one case lies unconformably on the lower), consisting of a great development of marls, shales, quartzites, and sandstones, and thick interbedded volcanic rocks, including rhyolitic lavas and ashes and a group of extrusive and intrusive igneous basic rocks, the latter occurring as sills. This whole formation is similar to the Birrim System of the Gold Coast. The next group of beds has been termed the *Saionia Scarp Series*, for it makes a conspicuous feature as a scarp several hundred feet high. This series of sandstones and mudstones with occasional grits and conglomerates and capped by a great sheet of dolerite rests unconformably on the old crystalline rocks and on the Rokell River Series. The beds are unfossiliferous at Saionia, **but** a few miles west in French Guinea¹³ *Monograptus riccartonensis* and other Silurian fossils have been obtained in shales interbedded

with sandstones; marine Carboniferous fossils have also been found, so that probably several Palaeozoic formations are represented by the Saionia Scarp Series. There are ferruginous quartz-sandstones in the Kofiu Mountains and on the Talla Plateau which are said to resemble the 'Nubian Sandstone' of Egypt in lithological characters; they rest horizontally and undisturbed on the gneiss and have a wide distribution in the hinterland of the Ivory Coast of Senegal and in the basin of the Upper Niger. They may be partly of Palaeozoic or even Mesozoic age, but there is so far no fossil evidence. Dolerites, often containing olivine, enstatite, or hypersthene, or rich in magnetite (*e.g.* in the Gowra country), are common amongst the intrusive rocks, but probably belong to distinct periods. They occasionally cover large areas, as in the Talla Plateau.

The uncompacted sandy formation known as the *Plateau Sands* exhibits a series of terraces suggesting intermittent uplifts¹⁸ in late Tertiary times after a deep submergence, and there are Pleistocene and Recent deposits on the coastal plain. Reddish laterite⁵, the product of prolonged weathering of the solid rocks, covers almost the whole country, and forms the chief building-stone. The whole Colony and Protectorate seem to lie on the same *massif* of ancient rocks as that which comprises French Guinea⁷ on the north and Liberia on the east, and is continued to the Ivory Coast.

ECONOMIC MINERALS^{12 20}

Iron.—Iron ore (titaniferous) occurs in various places. But the chief deposits of economic value are the masses of haematite which form two prominent hills near Marampa and occur in the Marampa Schists^{12 17}.

Diamonds^{9 16 20}.—These gems are found in alluvial and surface deposits on the Sewa River⁹, and in lateritic gravel on tributaries of the Gbobo and Bafi rivers¹⁶, as well as on the plateau of the Kono district²⁰. The diamonds are much larger than those on the Gold Coast¹¹, and there is an abundance of green stones. Most of the heavy minerals associated with them are sharply angular and must have been derived from local rocks. Granite is the prevailing rock in the diamond-field, but there are pendants and masses of schists, amphibolites, quartzites, and banded ironstones, with intrusive dykes of dolerite. The derivation of the diamonds from ultrabasic rocks connected with the dolerites which pierce the granites has been suggested²⁰.

Chromite.—This mineral occurs in the talc-schists and serpentines of the Kambui Series in the province of Kenema¹⁴.

Manganese is found in the weathering products of gametiferous granulites¹².

Molybdenite.—On the Mapoko River this mineral is found as impregnations in biotite-chlorite schist¹⁵.

Bauxite.—Wide areas of unknown extent are covered with this weathering product of various rocks.

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SECTION IV.—GAMBIA⁶

The geology of the British Colony and Protectorate, which covers over 4000 sq. miles and consists mainly of a narrow strip of land along each side of the river Gambia for about 250 miles in a straight line from its mouth, remains to be fully investigated, but we possess some knowledge of it and of the adjoining French territory on the north and south, and it may be conjectured⁷ that closely similar tectonic conditions and stratigraphical formations will be found to prevail in the Gambia from the Barraconda Falls to M'Carthy's Island; the river valley is enclosed by low rocky hills of a volcanic (?) nature, and ridges of ironstone cross the river in this part. According to Lemoine's⁵ map, the whole valley of the river in the British Colony consists of Miocene, Pliocene, and Quaternary deposits. But according to Cooper⁸, there are only three main divisions of the rocks, all of shallow-water formation, and the beds are often very local and lenticular. No fossils of stratigraphical value have been so far found in them. The lowest is the *Wallikunda Calcareous Sandstone*, containing a foraminifer (*Cristellaria*); it is a hard sandstone containing a large proportion of dark minerals⁸. The next is the '*Sandstone Series*,' consisting mainly of sandstones with important bands of clay, grit, and fine conglomerate. This formation is flat-bedded with a gentle dip westward, and conforms closely to the land surface of the plateau; it is mostly covered with a cap of pisolitic ironstone. It extends into Senegal, where it is proved to be of Eocene age by its fossils (see below), but part of it may be younger; the cliffs along parts of the river consist of this Series. The third formation consists of Pleistocene and Recent Raised beach deposits containing marine molluscan shells identified by Morley Davies⁸. The oldest rocks in the lower part of the river valley belong to the Wallikunda Series. No volcanic rocks are here present.

In the adjacent French colony of Senegal¹⁻⁴, lying to the north, there is a basement series of metamorphosed sediments (schists, limestone, quartzites, etc.), pierced by intrusive granites and diabases. Overlying these are horizontal siliceous sandstones, perhaps of Devonian age, like those in the Sahara. A strongly-folded and disturbed but richly-fossiliferous Cretaceous limestone is succeeded by laminated white clays, containing curious siliceous concretions and echinoids of Senonian age. Volcanic eruptions took place during Cretaceous times, as shown by the presence of associated tuffs. Phosphatic deposits, accompanied by marls, clays, and limestones, with sands and clays at the top, succeed the Cretaceous, and these beds yield a fauna with an Eocene facies,

including representatives of the genera *Ostrea*, *Schizaster*, *Linthia*, and *Nummulites*, together with fish teeth². A later limestone yields Miocene fossils. Pleistocene sands with a rich marine fauna occur near Dakar, and Recent sands, alluvium, ferruginous sandstone, and laterite cover much of the interior of the country. It is probable that some, at any rate, of these formations will be found in the British area.

To the south of the Gambia River, and traversed by its upper waters, there is a projection from the great interior mass of Primary rocks, consisting of much folded schists and quartzites traversed by various intrusive rocks. These seem to bound the valley on the south.

Economic Minerals.—Gold, iron, and tin occur as detrital grains in the sandstones and stream-sands, but are of little importance⁸.

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SECTION V.—THE CAMEROONS (BRITISH AREA)

General Characters.—The portion of the ex-German Colony of the Cameroons^{6 8}, now under British control, forms a long, narrow, wedge-shaped area adjoining Southern Nigeria, and widening south-westwards towards the coast so as to include the Cameroon Mountain.

In the Cameroon region regarded as a whole, three main geological provinces^{2 8} based on tectonic characters have been recognised, and bear a close relation to the surface-features of the country. The first province consists of the marginal band of sedimentary rocks near the coast, and includes Cretaceous, Tertiary, and Recent deposits, which are scarcely disturbed and are continuous with those of Southern Nigeria, though apparently possessing a slightly different development. The second province is a broken hilly region, composed of ancient crystalline and metamorphic rocks, and is usually sharply marked off from the unaltered sedimentary zone; it is broken up into great fault-blocks or horsts, troughs, and areas of depression. The third province constitutes the interior plateau or highlands, which is likewise composed of ancient crystalline rocks, but is less shattered, and is much dotted over with volcanic rocks of later date.

Throughout all three provinces there have been extensive volcanic⁷ eruptions from Cretaceous to Recent times, and the lavas and fragmental volcanic rocks form many conspicuous mountain masses, of which the most important in the British sphere constitutes the Cameroon Mountain on the coast.

DETAILS OF THE STRATIGRAPHY

Archaean, Pre-Cambrian⁸ (and Palaeozoic ?) Rocks^{12 4}.—The ancient crystalline and metamorphic rocks, the precise age of which is uncertain, form part of the same great African *massif* as Nigeria, and cover the largest superficial area in the whole Cameroon region, being specially developed south and east of the British sphere. From near Jabassi, on the Wuri River, near the Franco-British frontier, the boundary between the interior crystalline *massif* and the marginal sedimentary zone runs behind the Cameroon Mountain to the Hewitt and Anom Mountains, close to the old Nigerian frontier line, thus connecting the Oban Hills of Southern Nigeria. Inland the old rocks spread far into the interior. The oldest members of the crystalline rocks are gneisses and schists; biotite-gneiss seems to be predominant, but hornblende- and muscovite-gneiss are known. Amphibolites are frequently found interbedded with the gneisses. Of the schistose rocks mica-schists are typical and sometimes contain garnets, but other types of schist (*e.g.* quartz-schists) occur. All these rocks have been invaded by various plutonic intrusions, of which granitite is the commonest, but granite, syenite, gabbro, and diabase also are represented. The western part of the Manenguba Mountains

consists of a coarse diabase, and a banded green and red halleflinta has also been found in them. The Rumpi Mountains are composed of granite and gneiss. These mountains, to which may be added the Bafarami Mountains, are examples of 'horsts.' Pre-Cambrian rocks of sedimentary origin are little developed, but in the northern part mica-schists, phyllites, quartzites, and crystalline limestones have been recorded⁶, and in the eastern part of the middle portion similar rocks and some graphitic schists are found. In many places there is a network of quartz-veins carrying pyrites and occasionally gold⁶. The strike of these Pre-Cambrian rocks is chiefly to the north-north-west.

It is possible that some of the intrusions of quartz-porphry and diabase, and the dykes of aplite, pegmatite, bostonite, etc., in the crystalline areas are considerably later in date than the massive plutonic rocks, but they are certainly older than the Cretaceous. In the pegmatites tin and wolfram as well as mica in large slabs (as at Mamfe) are known to exist⁸.

In northern Adamaua, and in Muri, there is some evidence of a Palaeozoic transgression, for there are sandstones and clay-slates containing badly preserved brachiopods of an ancient type, and forming trough-folds in the crystallines near Dakume and Bulo³; the fossils are stated to be like those in the Tuareg highlands of the Sahara.

Cretaceous.—The Cretaceous beds occur in the coastal province only, and consist of sandy and shaly clays interbedded with sandstones; in the upper part there is a richly fossiliferous limestone⁷. Rocks of this age encircle the Oban Hills, forming a narrow coastal band along their southern border, and running as such south-eastwards to the Mungo River and beyond it. On the Cross River, to the north-east of the same hills, the Cretaceous outcrop widens and sends a narrow strip southwards to join the coastal band. The volcanic Cameroon Mountain interrupts the continuity of the latter. A broad band on both sides of the Benue River runs north-east into the interior, as shown on Behrend's map⁷.

Both Lower and Upper Cretaceous beds are present in the area. The Lower beds are arenaceous or shaly, and sometimes bituminous, and on the Cross River in the Ossidinge district bituminous shales, conglomerates, and calcareous sandstones are interbedded with the sandstones, and rest directly on the granite, but are older than the overlying basalts. Some carbonaceous plant-remains have been found in them, and on the tributary Mamfe River black shales have yielded fish-remains belonging to the genus *Proportheus*, and other genera. It is probable that some of these beds may be correlated with the Benue Sandstone of Nigeria. Locally the beds are somewhat disturbed and folded. On the Mungo River⁷ the Cretaceous beds have a thickness of not less than 40 metres, and usually dip at low angles, and the principal fossiliferous rock is a bluish grey massive argillaceous limestone. Santonian, Campanian, and Maestrichtian horizons are recognised. Ammonites are especially abundant, and include species of *Peroniceras*, *Mortoniceras*, *Tissotia*, *Pseudotissotia*, *Hoplitoides* and *Barroisiceras*, which are allied to the Upper Cretaceous forms in Algeria. Large species of *Lima* and *Cytherea* are associated with these ammonites, and in the more argillaceous portions the genus *Turritella* is abundant, and the genus *Actceonella* occurs, in addition to many genera of bivalves⁷. In complete conformity with these beds on the left bank of the Mungo River are calcareous clays and sandstones, alternating with beds of volcanic tuff of late Tertiary age containing dicotyledonous leaves⁹, indicating that volcanic activity began in Upper Cretaceous times.

Tertiary.—On the Mungo River, between Bakundu ba Bombe and Bakundu ba Nambele, there are fossiliferous marine finely-bedded **calcareous clays**,

almost horizontal, and containing numerous casts of gastropods and bivalves, of which the most abundant are *Turritella eschi*, *Cytherea nitidula* Lam., *C. elegans* Lam., *Tellina subrotunda* Lam., *Calyptrea trochiformis* Lam., *Sycum bulbiforme* Lam., and many new species of other genera allied to European Eocene forms. A considerable area of Tertiary beds is spread around Yola on both sides of the upper part of the Benue River.

Post-Tertiary and Recent.—Of undetermined but later age are widespread unfossiliferous loams, sands, conglomerates, and deposits of laterite. Probably they belong to various periods.

Volcanic Rocks.—Volcanic eruptions commenced in the Upper Cretaceous, but the chief outpourings of lava took place in the Tertiary, and there have been successive eruptions down to modern times. The oldest as well as many of the youngest lavas are basalts of several penological types^{4 5}, but are mainly olivine basalts and limburgites, and, together with basalt tuffs, they are widely spread over the crystalline rocks, forming in the whole Cameroon region one of the largest basaltic provinces on the earth's surface. In the Bakundu depression, bounded on the east by the Manenguba Mountains, these basalts have a great development, and numerous craters here exist, some of which contain lakes (e.g. the Soden Lake and Elephant Lake). The Cameroon Mountain itself is composed of volcanic material, chiefly basaltic⁶ lavas and tuffs ranging in age from Senonian to Recent. The plant-remains in the basaltic tuffs are said to belong to living species⁹ and thus indicate the recent date of these volcanic outbursts. The perfect and fresh condition of many of the cones and craters in the interior (e.g. in the Manenguba Mountains) also proves the late nature and recent age of some of the vulcanicity.

Trachyte plays the chief part amongst the later eruptive rocks of the interior, and there are several penological varieties of this type. Andesites have a very small development. The fracturing of the country seems to have been subsequent to the trachytic eruptions, according to Guillemain², but the whole area underwent a gradual elevation during the whole volcanic period. The volcanic activity is not yet extinct, and an outburst took place in 1909 in the Cameroon Mountain, while solfataras and fumaroles are still numerous.

The existence of a series of lines of fracture running in a general N.N.E. direction from the sea-coast inland to lat. 10° 30' N. and beyond is a remarkable feature in the Cameroons, and their course is marked by volcanoes and great outpouring of lavas of Recent or late Tertiary date. Though no definite trough has been formed by the dislocations, yet the south-west part of the Cameroons is said to exhibit a structure much resembling that of the south-west half of the East African trough; the association of volcanic eruptions with this zone of shattering is another feature common to the two regions, so that it may be suspected that the movements and volcanic phenomena belong to the same period, and are due to the same widespread cause.

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SECTION VI.—TOGOLAND (BRITISH AREA) I 2

In the western portion of the ex-German colony of Togoland^{7 8}, which has come under British control, there is the continuation of the rocks which occur in the adjoining parts of the Gold Coast and Ashanti. The basement⁵ rocks are of many different types, chiefly igneous, including diorite-gneiss, many kinds of schists and intrusions of serpentine, pyroxenite, etc.⁵, but they are more widely exposed in the French territory on the east, and are apparently the same series as are known in the south-east of the Gold Coast. Following on them are the metamorphosed sediments, the *Togo Series*, chiefly consisting of schists of various types (mica-schists, talc-schists, garnet-schists, quartz-schists, and phyllites), with quartzites chiefly developed along the western side, and, according to Lemoine³, continued north-eastwards to form the Atacora chain north of Dahomey. All these altered rocks Lemoine refers to the Silurian. They form a series of mountain ranges stretching across Togoland, continued from the Gold Coast north of Accra, and trending in a general north-easterly direction across the Volta River, and then bending round to assume a more northerly strike. In places the beds are vertical. There is another series of less altered and less disturbed sedimentary beds (the *Buem Beds*) consisting of arkoses, sandstones, conglomerates, quartzites, phyllites, and clay-slates, which Lemoine separates from the above-mentioned and refers to the Devonian, but they are described as probably pre-Cambrian in Ashanti; these occupy much of the western part of Togoland, and are especially developed in the Buem district. They rest unconformably on the Togo Series. No fossils have been found in them, but from the occurrence of certain supposed glacial conglomerates in the series a Permo-Carboniferous age has been assigned to them. The beds are pierced by a few small intrusions of diabase and porphyrite. There are also certain contemporaneous volcanic rocks⁷ in the Buem Series ranging from rhyolites to olivine-basalts, but the commonest types are basalts; with them are associated agglomerates and tuffs. The Buem Series is regarded as the equivalent of Kitson's Birrim Series of the Gold Coast. On both sides of the Oti River, and extending far to the west and inland, there are conglomerates, etc. (the *Oti Beds*) containing pebbles of the Buem Beds and lying in an undisturbed horizontal position. They are not pierced by any intrusive rock, and are provisionally referred to the Upper Cretaceous. According to Robertson⁷, the Oti Series is the equivalent of Kitson's Kwahu Series, and may be of Palaeozoic age, but there is no fossil evidence of any kind. In the

French area on the border of Dahomey there is a small patch of Eocene limestone at Tokpli^{6 8} containing, amongst other fossils, *Turritella esclii*, which occurs in the Eocene of the Cameroons. At Adabion, on the coastal plain, a rich fauna of lamellibranchs, gastropods, etc., of Lower Eocene age, equivalent to the Libyan stage of Egypt and the Ranikot beds of India, has been described⁶. The coastal region consists largely of alluvial deposits with some lignite, while laterite is found in the valleys.

Of minerals⁴ of value, iron, in the form of ferruginous schists (itabirite), is the chief one so far discovered.

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CHAPTER VII

ISLANDS IN THE ATLANTIC OCEAN, AND ANTARCTICA

SECTION I.—ASCENSION, ST. HELENA, TRISTAN D'ACUNHA

The British Islands of St. Helena and Ascension, with Tristan d'Acunha and Gough's Island far to the south, are of volcanic origin, and the three latter are situated on the submarine ridge which runs down the middle of the Atlantic Ocean from north to south, and is covered by an average depth of water of about 1700 fathoms, except where its projecting points, such as these islands and St. Paul's Rocks, rise above the surface¹¹ 17-19.

Ascension^{1-3 14 15}.—In the Island of Ascension, which is entirely composed of volcanic rocks, there is no trace of present activity, but the cones of tuff are so little altered and their contours so sharp, that the last eruptions which formed them must have been of recent date. Almost the whole surface is covered by flows of black scoriaceous basalt, but the central mass of the island consists mainly of trachytic rocks (alkali-augite-trachytes), and includes the heights of Green Mountain (2817 ft., the highest point in the island), Red Hill, and the neighbouring eminences. These trachytic rocks are described as underlying some of the younger basalts. They are usually of a pale brown colour, and many are laminated. Most of them are augite-trachytes, and obsidian (so-called 'hornstone') is associated with them. Fine whitish or greenish trachytic tuffs containing blocks of cellular porphyry also occur, and dykes of pyroxene-andesite harder than the surrounding rocks penetrate the trachytic series. According to Daly^{14 15} basaltic eruptions preceded as well as followed the trachytes; and in the case of Green Mountain 'its visible base is a large basaltic cone truncated by a major explosion. Into the resulting caldera a trachyte dome arose to a height of nearly 2400 ft. above the sea, and sent short thick flows towards the "Riding School" and the "Bear's Back." The eastern part of the dome and the trachyte flows alongside were blown away by a second explosion, forming another caldera nearly a mile long and 1000 yards wide. This caldera in its turn was completely filled with basaltic tuff, which, from a central vent, was built up to a height somewhat greater than 2817 ft., forming the present

elevation of the "The Peak" of Green Mountain.' Endogenous trachyte-domes as crater-infillings are a feature in the island, and calderas formed by paroxysmal explosions are conspicuous. The series of lavas is identical in general sequence with that at Tutuila, Samoa, beginning with common olivine-basalts and passing through a succession of types to alkaline quartz-trachytes (rhyolites¹⁵) and back to basalts. The sequence¹⁵ also agrees with that in the Tertiary lavas of Somaliland, Madagascar, New South Wales, and Victoria. Rhyolites and rhyolitic tuffs are also found in places on the island (*e.g.* on Red Hill). Prior¹⁰ says that most of the so-called trachytes are of a distinctly phonolitic type rich in soda, and that the associated obsidians are their glassy equivalents and have the chemical composition of soda-rhyolites.

As shown by Daly¹⁵, some of the basaltic lavas are younger than the trachytic rocks and rest upon them and surround them. The flows are traceable to points of eruption at the base of the central mass or to separate cones scattered over the western and northern borders of the island. The summits of these cones are often obliquely truncated as a result of the north-east trade winds. The lava-flows, which are either massive or vesicular, and have their surface very scoriaceous and rugged, form nearly the entire circumference of the island. Thick layers of scoriae are intercalated between them, and it has been stated that near Green Mountain and Red Hill¹⁵ they contain ejected masses of amphibole-granite, granitite, diabase, and gabbro, indicating a continental basis for the island³, but the occurrence of granitic rocks is questionable. Apart from a deposit of diatomaceous material in one of the craters and some Recent calcareous formations on the sea-coast, only igneous rocks are known on the island.

St. Helena^{14 16}.—This island, which has an area of about 45 sq. miles, lies about 700 miles south-east of Ascension, and is bounded on the east, north, and west by perpendicular cliffs from 450 to 2000 ft. in height. Its interior is formed of an elevated plain with a nearly central curved ridge, 2000-3000 ft. high, known as Sandy Ray Ridge, bounding a depressed saucer-like area surrounding Sandy Bay on the south coast, and measuring about 4 miles across. The ridge is generally supposed to represent a crater-wall, like the Caldera of Palma, which has been broken away on the south side. Daly¹⁶, however, considers that the basin form is due to erosion and does not indicate an explosion crater or circumferential faulting as has been suggested. The island is wholly of volcanic origin, but is older in origin and more dissected than Ascension. It is largely composed of basaltic rocks with or without olivine. The abundance of dykes, which are so rare on Ascension, is a most striking feature, and the most conspicuous ones are grouped in

two systems^{14 16}. The lavas seem to have been poured out by fissure-eruptions, but some of the fissures have been locally enlarged into necks by explosion or other causes. The building of the great composite exogenous Sandy Bay dome was due essentially to eruption from many fissures in a limited area^{14 16}. Some of the basalts are rich in olivine, but the majority are poor in that mineral.

Darwin¹ distinguished two series of lavas, comprising 'a lower series of flows of basaltic lava separated by laminated tuffs with rounded pebbles, bright red saliferous tuffs, layers of scoriae, and bands of brilliant red, yellow, and purple volcanic mud and laterite. The lava-flows in this series number 60 or 70 and dip slightly seawards, breaking off in lofty cliffs, up to 2000 ft. high, and covering the northern and western parts of the island. The central and eastern parts were held to consist of later grey felspathic lavas or trachytes, generally much decomposed. But Daly¹⁶ maintains that Darwin's two series of lavas, 'basalts and grey felspathic lavas' are both basaltic and show no differences in mineralogical or chemical characters. The dominant rocks of the main *massif* are bedded basalt lava-flows of an average thickness of about 16 ft., and have centrifugal dips from a focal area in the Breat Basin. The rocks of the north-eastern *massif* include tuffs and breccias. In both areas the profusion of dykes and sills, especially vertical dykes, is conspicuous. 'Each *massif* in the Island is an exogenous dome recalling the domes of Hawaii,' according to Daly¹⁶. The floor of the crater, which is girdled by the central ridge, is dotted with hillocks of scoriae and masses of highly cellular and amygdaloidal lavas. More than one lateral cone (*e.g.* High Knoll) existed outside the limits of the central crater, and ejected its own lavas.

The dykes and sheets of porphyritic basalt with glassy margins which traverse all the above-mentioned volcanic beds were injected subsequent to these eruptions from the main crater, near the centre of which they increase *in* number. Three or four of these largest dykes strike in parallel lines from north-east to south-west across the crater, and form remarkable features on the surface.

The conical hills, dykes and columns of phonolite¹⁰ and phonolitic trachyte, which frequently stand up above the general surface of the ground in fanciful shapes, belong to a still later period of eruption, and one of the columns, rising to a height of 260 ft., is well known as 'Lot's Wife.'

Of superficial deposits there **are** sand-dunes; there is a calcareous sandstone also of æolian origin, containing well-rounded fragments of shells and other organisms, frequently cemented together to form a hard compact rock. Some of the species of mollusca in it are extinct, or are no longer living on the island, but others still exist on it. The thickness of this deposit varies from

2 to 15 ft., and it occurs up to a height of 700 ft., but this is due to wind action. Beds of extinct land-shells, more or less consolidated by calcareous matter, are also found beneath the vegetable soil.

It appears that the island commenced as a submarine volcano which was gradually built up above the level of the sea by successive outpourings of lava and of fine ashes, which accumulated first as volcanic muds on its gently sloping sides beneath the water. The large crater of Sandy Bay Ridge which was ultimately formed in this way was subsequently breached by the sea, probably after an explosive eruption, like that of Krakatoa or Barren Island in the Indian Ocean. With the dying-out of volcanic activity the continuation of marine erosion has cut back the margins of the island so as to produce the lofty cliffs which now surround it on three sides, and has destroyed all the southern portion of the central crater. Judging from the gentle average dip (6° - 10°) of the principal series of lava-flows, the size of the island must have been enormously reduced since its elevation and the cessation of eruptions. Local upheaval has caused the tilting of the strata at high angles in some places, as may be seen at 'The Barn,' on the north-east coast of the island, but in most cases the dip of the beds seems to correspond with the original slope of the lava-flows and tuffs. With regard to the relations of the volcano of St. Helena with others, it is considered by many to belong to the long rectilinear series of volcanoes running in a general N.N.E. direction from Anno Bom to Fernando Po, **and** thus on to the mainland of the Cameroons. The lines of fracture in the south-west part of the Cameroons have a similar course, and this 'Cameroon line' extends inland at least as far as lat. $10^{\circ} 30' N$. There is no proof of an old basement of plutonic or sedimentary rocks^{16 19}.

Tristan d'Acunha.—Tristan d'Acunha^{3 4 20 20a}, Inaccessible Island, and Nightingale Island, with several neighbouring islets, are situated at the southern end of the submarine ridge which runs down the centre of the Atlantic Ocean¹⁷⁻¹⁹. Tristan d'Acunha rises almost vertically out of deep water, and is encircled by lofty perpendicular cliffs on the top of which is a plateau 1000-2000 ft. above the sea. On it rises a central cone to a height of over 7600 ft. The island is composed of nearly horizontal flows of basalt alternately compact and scoriaceous, with intercalated layers of reddish volcanic tuff, and these beds are traversed by numerous vertical dykes mainly composed of feldspathic basalt, but sometimes passing into augite-andesites, and producing alteration in the contiguous rocks. Trachyte also occurs. There is no trace of recent volcanic activity. The central peak is stated to consist of black and red scoriæ, and has a crater-lake at the summit. Several other smaller eminences on the

plateau may represent secondary cones of eruption. Evidence of a continental foundation for the island is furnished by a block of gneiss ejected by an eruption^{3 9 19}.

Inaccessible Island^{20 20a} has an identical geological structure. Most of the lavas are felspathic basalts, generally porphyritic; palagonitic tuffs also occur. Dykes of basalt with glassy margins cut the bedded flows.

Nightingale Island^{20 20a} is described as having the coast chiefly composed of a conglomerate or volcanic breccia of doleritic fragments imbedded in a whitish felspathic matrix. The rock seems to be a phonolitic tuff or agglomerate, and has numerous minute crystals of nepheline imbedded in it. Andesitic rocks are also found in some places on the coast, and a raised beach and caves above sea-level point to a recent movement of elevation.

Gough's Island^{7 8 11 12 20 20a} lies about 240 miles south-west of Tristan d'Acunha, and is probably a volcanic cone, forming a craggy mass which rises to a height of 4350 ft., but much of it consists of a plateau about 300 ft. above sea-level. It is made up entirely of volcanic rocks, so far as is known, and chiefly of a series of lavas forming horizontal flows which break off in cliffs 200-1000 ft. high. The lavas comprise soda-trachytes, characterised by an abundance of anorthoclase feldspar, and trachydolerites in which olivine is also present. Trachy-basalts and mugearites have also been described^{20a}. Trachytic tuffs occur, and intrusions of basalt forming dykes with trachylitic margins, and of essexite, have been found piercing the lavas.

The alkali-trachytes seem to resemble those occurring on Ascension.

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SECTION II.—THE FALKLAND ISLANDS

This group of islands^{1 3}, about 100 in number, lies 480 miles north-east of Cape Horn, and has an area of about 6500 sq. miles. The two principal islands, known as East Falkland and West Falkland, have a much indented and irregular coast-line, and a wild rugged interior, with hills rising to heights of over 2000 ft. The lowlands and valleys consist mostly of clay-slates, locally much folded, and the hill-ranges of hard quartzites with subordinate bands of slate. All these rocks were thought to be of Palaeozoic age, comprising Devonian and Permo-Carboniferous beds resting on an Archaean foundation, but the uppermost beds are probably Triassic, according to Baker. The succession of beds is essentially similar to that in the Cape Colony, South Africa, as has been long recognised, and Baker¹⁸ following Halle³ has made a close correlation. There are two main groups of strata, the upper of which is termed the *Lafonian*, corresponding with the Permo-Triassic of the Karroo System of South Africa and its equivalents in India (Gondwana), Australia, and South America, while the lower group, which is separated by an unconformity from the upper, corresponds with the Lower Devonian of Cape Colony and parts of South America, and with the Middle or Upper Devonian of Cape Colony as represented by the Witteberg Beds. These Devonian beds constitute a pre-Lafonian group.

DETAILS OF THE STRATIGRAPHY

Archaean.—These rocks are exposed only at Cape Meredith^{310 18} on West Falkland and consist of pegmatite, granite, gneiss, hornblende-schist, and quartzite, with some intrusive lamprophyre dykes. Baker¹⁸ suggests their correlation with the Kama System of South Africa.

Devonian.—With the exception of the southern half of East Falkland and two small areas on West Falkland, the whole of the islands are composed of Devonian rocks. These rocks consist of a great series of quartzites, sandstones, and slates, and rest unconformably on the eroded Archaean foundation as seen at Cape Meredith, having a fine conglomerate at the base. Over large areas in the islands the beds are horizontal and undisturbed, but within a zone stretching from Port Stanley westwards to Falkland Sound, and continuing on West Falkland in a north-westerly direction, they have suffered plication.

Fossils^{12 6 7} are found in the softer rocks, the sandstones and slates of the lowlands and valleys, but mostly in the sandstones. On Pebble Island the fossils occur in calcareous nodules in a very fine-grained black slate. The fossiliferous beds occur at Port Louis, Port Salvador, San Carlos, and Fox Bay. The fauna is of Lower Devonian age, and bears a close resemblance to that of the Bokkeveld Beds of South Africa⁹, many of the species being identical

(marked (B) in list), and others are closely allied. The following may be mentioned:—

(B) *Homalonotus herscheli* Murch., (B) *Leptocælia fldbellites* Conr., (B) *Orthothetes (Schuchertella) sullivanii* Morr. and Sh., (B) *Chonetes falklandica* Morr. and Sh., (B) *Cryptonella (?) baini* Sh., (B) *Spirifer orbignyi* Morr. and Sh., (B) *Spirifer antarcticus* Morr. and Sh., (B) *Orbiculoidea baini* Sh.

Of a total of twenty-eight identified species in the Falkland Islands, eighteen are Bokkeveld species. Fragments of a lepidodendroid plant also occur¹¹.

The fauna, as well as possessing very close affinities with that of the Lower Devonian (Bokkeveld Beds) of South Africa, bears marked but less intimate relations to that of the equivalent rocks on the mainland of South America¹², such as the Icla Slates of Bolivia⁵ and Brazil⁶, many of the species being identical. This widely distributed austral fauna is in strong contrast to the boreal Devonian fauna, and was developed in a distinct zoo-geographical province¹⁸ more or less completely and continuously separated from the northern one, but not necessarily by land-barriers. But Allan¹⁶, in discussing the fauna of the Reefton (Lower Devonian) beds of New Zealand (q.v.), sees more resemblances than differences between the boreal and austral faunas, and stresses the occurrence of a few cosmopolitan species.

Baker divides the Devonian, or partly Devonian, beds thus in descending order:—

Port Stanley Beds (quartzites, with intercalated shales).

Part Philomel Beds (sandstones, shales, and flagstones with lepidodendroid plant-remains).

Fox Bay Beds (sandstones, shales, and slates, with abundant Lower Devonian fossils).

Port Stephens Beds (sandstones, quartzites, and quartz-conglomerates).

The total thickness of these beds is uncertain, but is probably 10,000 ft. The Port Stanley Beds form the heights of the northern part of the Colony. The Fox Bay Beds are typically developed at Fox Bay, West Falkland. The Port Stephens Beds are unfossiliferous and occur in the southern half of West Falkland.

Halle³ and Baker^{10 18} correlate the basal group with the Table Mountain Sandstone of Cape Colony, but regard the fossiliferous beds as in general equivalent to the Bokkeveld Beds, while Halle considers the hard quartzites as possibly representing the pre-Karoo Witteberg Beds of the same region. The unfossiliferous basal Port Stephens Series is nearly horizontal and of great thickness, probably about 5000 ft., while the Middle and Upper Series each include about 2500 ft. of sandstones, quartzites, and shales.

Caster¹² considers that the Devonian strata in these islands apparently represent 'a marine encroachment on the crystalline old-land,' and that the pre-Andean geosyncline 'gave way towards the south to a broad seaway,' with the 'Austro-Brazilia Shield' to the north-east, and the 'Austro-Andean' old-land to the south. Clarke¹⁸ held different views, and considered that the continental mass 'Falklandia,' around which the southern Devonian shore-faunas developed, was 'the parent land-asylum out of which, in post-Carboniferous time, Western Gondwanaland and Antarctica were carved.' Baker¹⁸ regards the Falkland Islands as forming a portion of Patagonian Gondwanaland in Permo-Triassic times and as lying near the northern shore-line of a land-mass which extended west and north-west to the Santa Cruz and Rio Negro areas of Patagonia, but was separated by a stretch of sea from the northern land-mass of Brazilia. By Wegener's theory of drifting continents and the

splitting off of South America from South Africa the problem of their close stratigraphical and structural resemblances finds a plausible solution.

The plant-remains¹¹ from the Port Philomel Beds occur at several places, and their lepidodendroid characters suggest that they come from the horizon of the South African Witteberg Beds.

Permo-Triassic³.—According to Baker¹⁸ there is an unconformity between the Devonian and the Permo-Triassic groups of rocks. This upper group, which is termed the *Lafonian Series*³, is divisible into two parts, of which the lower is marked by the presence of a glacial tillite or boulder bed forming the base except for a local development of shales and sandstones below it. Following the boulder beds are varved slates and then sandstones with scattered erratics.

This lower part of the Lafonian Series is classified by Baker¹⁸ as follows, and is estimated to be about 2400 ft. thick; it is apparently unfossiliferous :—

Lafonian Sandstone (fairly fine-grained sandstone with erratics in lower part).

Black Rock Slates (cherty beds and slates).

Lafonian Tillite (glacial boulder-beds).

Bluff Cove (Fitzroy Basin) Beds (shales and sandstones occurring only locally).

The upper part of the series is the thickest (9250 ft.) and is as follows in descending order¹⁸:—

West Lafonian Beds (alternating sandstones and shales).

Bay of Harbours Beds (claystones, shales, and sandstones with *Glossopteris* flora).

Choiseul Sound and Brenton Loch Beds (varved shales).

The glacial tillite which corresponds with the *D wyka* tillite of South Africa and the Talchir of India, consists of a mudstone matrix devoid of stratification, and holding angular, sub-angular, and rounded boulders, some of which are polished, striated, or faceted, and represent a great variety of rock-types, including mostly granite, gneiss, and quartz-porphyry with quartzites, sandstones, slates, and diabases. The tillite forms a continuous belt of country in East Falkland stretching east and west right across the island, but in West Falkland is restricted to a narrow band on the east coast. The basal beds of this upper part of the Lafonian Series consist of varved or laminated shales indicating seasonal changes. The Bay of Harbours Beds contain the *Glossopteris* flora. The plants include the following species :—

Phyllothea australis Brong., *Glossopteris browniana* Brong., *Glossopteris indica* Sch., *Glossopteris angustifolia* Brong., *Glossopteris damuaica* Feist., *Dadoxylon lafoniense* Halle, *D. bakeri* Seward¹¹.

The assemblage is of the typical Lower Gondwana type found in the southern hemisphere, and all the species are members of the widespread *Glossopteris* flora. One wing of an insect belonging to the *Lihomantidæ* (Handlirsch) has also been discovered.

The range and relations of the *Glossopteris* flora have been described in connection with the Karroo Beds of South Africa, and will be further mentioned in discussing the Gondwana Beds of India and the corresponding beds in Australia.

Igneous Rocks of Uncertain Age.—From the Permo-Triassic till the Quaternary period no deposits seem to have been laid down in the islands, but igneous rocks (diorites and dolerites) of uncertain age pierce both the Devonian and Permo-Triassic beds, and are all

in the form of dykes which often run parallel to the strike of the folds for miles.

Quaternary⁹.—On the shore of West Point Island there is a bed of clay lying on a black vegetable soil full of tree-trunks, amongst which *Podocarpus*, *Libocedrus*, and *Fitzroya* have been identified. The deposit indicates the previous existence of luxuriant forests such as now live in the temperate zones of South America.

Overlying this formation is a clay, containing large angular blocks and pebbles without stratification, and of the nature of a glacial deposit. Prior to and during this Ice-age the islands stood at a considerably higher level and formed part of a larger land-area, the surface of which was carved out into valleys now forming some of the sounds.

Tectonic Features.—Over large areas the Devonian and Permo-Triassic beds remain in a horizontal position, but in the northern parts of the islands there has been a post-Devonian folding. In East Falkland the folded zone runs due east and west from the eastern coast to Mount Osborne, where it bends to the north-west and continues in this direction to the coast. In West Falkland the strike in the northern part runs from south-east to north-west or E.S.E. to W.N.W. The Permo-Triassic occurrences are outside the folded zone. The folds are mostly regular, but there are some overthrusts. The whole group of islands seems to owe its existence to the crossing of two sets of folds in this region. The folding probably took place at the close of Triassic times and synchronised with that of the southern part of Cape Colony¹⁸. The strike of the one set of folds in the north of the islands is mostly north-of-west and south-of-east and is the cause of the trend of the mountain ranges. The other set is seen in West Falkland and runs N.N.E.-S.S.W.

There is an obvious connection between the structure of the Falkland Islands and that of the Argentine pre-Cordilleras and the Sierra Pampeanas. The pre-Cordilleras show a continuous series of Permo-Carboniferous and Triassic rocks of Gondwana type, resting conformably on Devonian beds, and these show a close relationship to those of the Falkland Isles. The latter may be regarded as part of the border zone of Gondwanaland, which has been involved in the Andine folded belt. The dominating east and west strike of the mountain ranges in the Falkland Isles is parallel to the hypothetical continuation of the Fuegian Cordillera, but, as Suess held, the ranges do not appear to be part of the South Antillean arc^{14 16 17}, which is continued into South Georgia (*q.v.*) and beyond.

' **Stone-Rivers.** '—The peculiar ' stone-rivers '^{13 4 8 18}, which are a

feature in the islands, consist of wide tracks of stones filling valleys at the eastern end of the principal island, and range in width from 100 to 1000 yards. They are regarded as due to the movement of sub-aerial land-waste produced during the Ice-age, and to the downward flow of mud-rivers on the melting of the snow. The stones consist mainly of the pale grey quartzites of the hills, and vary in length from 2 to 20 ft. ; some are also of diabase and other rocks. The blocks are angular and not decomposed or rounded, and form extensive level beds. They are more or less overgrown with moss which fills up the interstices, and the movement of the rivers ' seems partly due to the expansion and contraction of this moss as it takes up or loses water, and partly to gravitation. The finer materials and mud between the stones have been carried off by running water. Subsequent to the formation of these screes, the islands suffered submergence⁹ to 70 metres or more below their present level, but later movements of elevation have led to the formation of Raised beaches.

ECONOMIC GEOLOGY

The search for coal and oil has so far proved vain, but some iron-ore of sporadic occurrence has been found, and the beach-sands may be of commercial value¹⁸.

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SECTION III.—SOUTH GEORGIA

The island of South Georgia⁸ lies between 54° and 55° S. lat. and 36° and 38° W. long. It is of an elliptical shape, about 110 miles long and about 29 miles broad at its widest point. There is a longitudinal range of mountains, the Allardyce Range, forming its major axis and running approximately north-west and south-east parallel to the strike of the rocks.

The rocks are chiefly sedimentary in origin. The oldest^{2 3 6-8}, which are exposed in Cape George Harbour and Cumberland Bay, have been termed the *Cape George Series*, and consist of greyish-green quartzites, siliceous phyllitic slates, and black slates, much crushed and veined by quartz.

The overlying stratified rocks, which belong to one great series, form the greater part of the island, and are known as the *Cumberland Bay Series*^{2 3}, divisible into a lower, middle, and upper group, and they are separated by a marked unconformity from the older rocks. The lowest group consists chiefly of black shales and greywackes with much volcanic debris. Obscure fossils^{3a 12} occur in these beds. The middle division, of which the prevailing colour is rusty brown, consists of cleaved mudstones, siliceous shales or grits, and a few bands of dark limestone, one of which shows traces of organic structure (radiolaria) and others contain much volcanic ash. Fine trachytic tuffs with detached crystals of orthoclase and oligoclase rarely occur. The upper division is of a general creamy white colour, and is largely composed of these tuffs, some of which contain also andesitic and latitic fragments. Amongst the many types of igneous rocks⁴ are spilites, which are characteristically associated with rocks of Palaeozoic or pre-Palaeozoic age⁵. Greywackes, mudstones, and black shales are also present, and some of the rocks contain radiolaria.

The rocks of the lower division have suffered more metamorphism than the others, and are often minutely puckered and folded. An intrusion of diabase or ophitic gabbro has been noticed in this lower group, and a boulder of quartz-monzonite-porphyry has been found in a moraine.

An igneous centre occurs at the south-eastern end of the island, possessing basic and some acid eruptive rocks, including gabbro, peridotite, basalts, granites, etc.

The fossils^{3 3a 12} are mostly obscure and of doubtful determination; those in the lower division are fucoids or sponges and may be Cambrian or Silurian, and in Cumberland Bay the impression of a *Posidonomya* suggests young Palaeozoic rocks¹. The plant *Aran-*

carioxylon has been identified from a rather uncertain horizon, but would point to an age not older than Lower Carboniferous and probably Mesozoic. The radiolaria of the middle division suggest a Jurassic age, and an ammonite which has been doubtfully identified as *Acanthoceras*, with fragmentary lamellibranchs¹², points to the probable presence of Cretaceous beds. But the Cumberland Bay Series forms one continuous succession, and each division includes bands of tuff and layers containing radiolaria, so that similar conditions seem to have prevailed during the whole period of its deposition.

The rocks are stated to be lithologically similar to the graptolite-bearing rocks of the South Orkneys (see below), which likewise contain spilites, and the islands may together be a remnant of an ancient continental land which once occupied the South Atlantic, and probably corresponded to Schwarz's 'Flabellites Land.' This view^{7 15}, which still finds favour in some quarters, is that * the trend of South Georgia and the South Orkneys is due to their being both parts of a dismembered South Atlantic land-mass' instead of parts of an Andean-Antarctica loop, as Suess held. But the igneous rocks are of the Atlantic and not the Andean type^{3 4}. Stocks¹³ considers that there can be no doubt that the island lies on the South Antillean arc¹⁴ which bends back in a great loop to carry the South Orkneys and South Shetlands; the distribution of the islands, their structure and the soundings in the neighbouring sea strongly support this conclusion. The west-to-east line of the Falklands is prolonged eastwards to South Georgia, then to the South Sandwich Islands, and then makes a sharp curve back to the South Orkneys and South Shetlands, and thus to Graham Land. The South Antillean Sea lies in the loop, and the Weddell Sea lies to the south-east below the loop, according to his map. Wilckens⁹ has made a comprehensive survey of the evidence and of the various theories regarding the relations of this and other islands to the mainland and to each other.

There is evidence of the former wider extension of the existing glaciers, and this extension probably corresponded with that indicated in Tierra del Fuego and the Antarctic Regions. Several rock-platforms near the coast-line point also to recent movements of subsidence and elevation.

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SECTION IV.—GRAHAM LAND

General Characters^{1 3 5 11}.—This high mountainous region in the Antarctic presents a remarkable similarity to the southernmost part of South America. Not only are the outlines and orography much alike, but the geological structure of the two regions is strictly symmetrical, and the sequence and relations of the strata are in close agreement. There is in both (1) a western tract of folded and igneous rocks with the outermost portion partly submerged and constituting a coastal zone of islands (with a few active volcanoes), and (2) an eastern tract of Cretaceous, Tertiary, and Recent formations lying in an almost horizontal position, and associated with basic volcanic rocks of Tertiary age. The strata, moreover, agree in general petrological characters and in organic contents, and point to simultaneous periods of submergence and upheaval in the history of this region. Wilckens¹⁰ maintains that the Terra del Fuego Cordillera is continued from Staaten Island into Graham Land and that all belong to the South Antillean arc.

Stratigraphy.—The tract of folded rocks on the west consists chiefly of plutonic types, closely related to the peculiar igneous rocks of the Andes^{1 2 11}, and comprise members of the granite-diorite-gabbro series, with quartz-diorite as the most abundant member. The age of these eruptives is somewhat uncertain, but, judging from the relations of similar rocks in Patagonia, they are either late Cretaceous or early Tertiary, and their intrusion was probably accompanied by the mountain-building. Probably the pebbles of crystalline rocks (granites and granophyres) in the Miocene beds of shingle were derived from these eruptives.

At Hope Bay at the north end of the mainland there are folded greywackes, overlain by dark slaty rocks which have yielded an abundant Upper Jurassic flora³; this is closely similar to that of the Jurassic of England, but also contains many species of the Upper Gondwana beds of India. The genera include *Otozamites*, *Zamites*, *Nilsonia*, *Thinnfeldia*, *Sphenopteris*, *Cladophlebis*, etc. These beds are succeeded directly by unfossiliferous light grey tuffs, some derived from acid volcanic rocks. In southern Graham Land¹¹ the succession is as follows: (1) Basement of gneisses and schists; (2) Plutonic intrusions, both basic and acid, but granites and granodiorites predominating; (3) volcanic and pyroclastic rocks, comprising andesites, dacites, tuffs, and volcanic breccias. The eastern part of Alexander I. Land on the west side of King George VI. Sound shows a stratified deposit of limestone, calcareous grits, and shales containing poorly-preserved mollusca and plant-remains

which appear to be like those in the Upper Jurassic beds of Hope Bay.

The most eastern geological tract of the area comprises Snow Hill and Seymour Islands³, and these contain the formations next in stratigraphical order. Those are of Upper Cretaceous (Senonian) age, and consist mostly of soft sandstones of more than one type and horizon. In places they are crowded with ammonites, which are the characteristic fossils, but they yield also other mollusca, corals, etc. The ammonite genera *Phylloceras*, *Lytoceras*, *Desmocerases*, *Kossmaticeras*, *Pachydiscus*, and *Anisoceras* are represented, and have a typical Indopacific character³. The whole facies of the fauna is of this type, and amongst the ammonites, bivalves, and gastropods species allied to or identical with those found in beds of this age in southern India, South Africa, and all round the Pacific Ocean have been recognised.

Tertiary marine sandstones of similar character follow conformably on the Cretaceous beds in Seymour Island, and contain an Upper Oligocene or Lower Miocene assemblage of mollusca, etc., like that of the Patagonian Molasse, but some New Zealand and South Australian forms also occur³. A plant-bearing bed occurs at the base of the series, and small conglomerates composed of pebbles of crystalline rocks are common. In one of the conglomerates on Seymour Island vertebrate remains, including *Zeuglodon* and extinct genera of penguins³, have been thought to indicate an Eocene age for the deposit.

Between the mountainous region of Graham Land and the above-described islands with Cretaceous and Tertiary sediments comes the Ross Island region, which is almost entirely composed of basaltic tuffs¹⁻³, horizontally bedded, with intercalated lava-flows of basalt, accumulated under sub-aerial conditions. The tuff rests in places on Cretaceous beds, but in Patagonia a similar tuff-formation rests on the Oligo-Miocene Molasse, and probably is of the same age.

Of later date than these volcanic rocks, and resting directly on them on Cockburn Island, is a conglomerate composed largely of their debris together with some pebbles of gneiss and granite. This deposit is full of a species of *Pecten* (*Myochlamys*) and of bryozoa, and is probably of Pliocene age. In Patagonia at Cape Fairweather a deposit with the same characters and relations is known to occur.

Subsequent to the depression accompanying the formation of this conglomerate there took place the maximum glaciation of the whole area during a period of elevation and dissection of the area, as in the case of the Falkland Islands, and it was followed by several oscillations in the level of the land, which are marked by Raised beaches.

SECTION V.—SOUTH SHETLAND, SOUTH ORKNEY
AND OTHER ISLANDS

SOUTH SHETLAND ISLANDS

In the South Shetlands⁷⁻⁹ the volcanic eruptions belong to three distinct series, the oldest of which consists of andesites with tuffs and interbedded mudstones; these are regarded as pre-Tertiary. The next beds are of basalts with basaltic agglomerates and olivine-andesite, and probably include the dykes of diorite; a Middle Tertiary age may probably be assigned to them. The last series comprises basalts and palagonite tuffs, the eruption of which lasted into Recent times. The determination of the respective ages of the series rests on indirect evidence from the occurrence and relations of Jurassic, Cretaceous, and Tertiary beds on neighbouring islands. In Elephant Island there are albite-schists resembling those of the Dalradian rocks in Scotland.

SOUTH ORKNEY ISLANDS^{22 30}

This group lies about 200 miles east of the South Shetlands and 800 miles south-east of Cape Horn, and it resembles South Georgia in general geological character. Shales and greywackes folded along lines running N.W.-S.E. or N.N.W.-S.S.E. are the principal rocks, and in one island have yielded a graptolite (*Pleurograptus*) and a supposed *Discinocaris*, which point to an Ordovician age⁴. No Pre-Cambrian or Jurassic rocks have been recognised as in South Georgia. The structural relations of these islands to the South American Cordillera and to Graham Land have been somewhat disputed, but they are probably on the same line of folding. As previously stated in the case of South Georgia, Wilckens¹⁰ maintains that the South Antillean arc of islands consists of fragments of the continuation of the Tierra del Fuego Cordillera³¹, and that it extends into Graham Land from Staaten Island, the folded rocks being all of the Flysch character and including porphyrites, tuffs, and andesites of probably Mesozoic age. The intrusion of granodiorite and gabbros, which he holds to be of Andine type, has produced metamorphism in them (see under 'Graham Land').

The succession of rocks in the various island groups of the South Antilles as given by Wilckens¹⁰ is as follows, though the whole series of formations is not present on every island :

- (1) Dark argillaceous and arenaceous rocks of a Flysch character, without any calcareous deposits, all much folded and having porphyritic tuffs and porphyrites interbedded. Probably Mesozoic in age.

- (2) Upper Cretaceous and Tertiary beds, not folded, including glauconitic and foraminiferal deposits.
- (3) Granodiorites and gabbros intruded into the folded series No. 1.
- (4) Tertiary eruptive rocks, including bandaites, andesites, and basalts.
- (5) Recent volcanic rocks (dacites, andesites, and basalts).

It has been suggested that South Georgia and the South Orkneys formed part of the hypothetical Tertiary continent of Antarctica, which has been postulated to account for the faunal and floral relationships of South America, South Africa, and Australia. Stocks¹⁵ would place all these South Atlantic islands on the same, but strongly bent, arc.

SOUTH SANDWICH ISLANDS¹²

Basaltic rocks of comparatively recent date compose this group of islands, which lies about 250-300 miles south-east of South Georgia. Some active volcanoes have been observed. Olivine basalts appear to be the principal type of lava, and alkaline rocks are completely absent^{6 17 18}. Tyrrell¹² describes dacite lavas with flow structure, and hypersthene andesites.

HEARD ISLAND

Heard Island²³, 250 miles south of Kerguelen Island, lies in 53° S. lat., 73° 30' E. long., and consists largely of volcanic rocks, including basalt, limburgite and limburgite tuffs, with some phonolite and andesite. But the most interesting fact is that grey crystalline limestone containing bryozoa and *Globigerina* occurs also in it.

SECTION VI.—OTHER ANTARCTIC REGIONS^{16-19 24 25 32}
(BRITISH SPHERES)

A general review of the geology of Antarctica has been lately given by Wade²⁴, but the papers by Furon²⁵ and Pollog³³ may also be consulted.

The **Ross Dependency**^{19-21 32}, lying between 150° W. long. and 160° E. long., comprises a wedge-shaped area including South Victoria Land, the rocks of which have been described by Debenham²⁶, David and Priestley²⁷, and others²⁸. The structure and tectonic geology of the Queen Maud Mountains at the south end of South Victoria Land have been described by Gould²⁹.

Eastern Antarctica appears to be a faulted horst, thus differing from Western (Pacific) Antarctica. The geological formations observed in it include a basement of metamorphic rocks (crystalline limestones, schists, and gneisses). Slates and greywackes¹⁹, possibly Lower Palaeozoic, follow after an erosion interval; then come plutonic rocks (granites, pink and grey) which, with dykes of other types, intrude the slates. The *Beacon Sandstone*^{19 26 28} of nearly horizontal beds with plant-remains and fish scales, and estimated at 5000 ft. thick, rests unconformably on the above-mentioned. The Permo-Carboniferous fern, *Glossopteris indica*, has been found in the upper part of the series¹⁴, and fish-scales of Devonian age occur near its base. After the deposition of the Beacon Sandstone, there was a hiatus ended by the intrusion of great sills of quartz-dolerite amounting to 4000 ft. in thickness and considered to be similar to the Cretaceous (?) dolerites of Natal and Tasmania¹⁹. A period of erosion, faulting and foundering then occurred, followed by a period of vulcanicity which began in Pliocene times and continued to the present day. The eruption of trachytes and phonolites was followed by that of kenytes, limburgites, olivine-basalts, and palagonite tuffs^{17, 21}. These volcanic rocks form most of the islands in the Ross Sea, and are also widespread on the mainland¹⁹.

Western Antarctica, in which the British sphere lies between 20° W. long. and 80° W. long., is related to the South American tectonic structure, and is traversed by folds of more than one period. The first is pre-Cretaceous. The peninsula of Palmer Land¹⁶, with its associated islands, is composed of three folded mountain-axes which have there converged from the Antarctic Continent and are a continuation of the Andean and South American mountain structure. The petrographic characters of the rocks¹⁸ are closely similar or identical, and have been described in many memoirs¹⁷. All the igneous rocks are genetically inter-related¹⁸.

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CHAPTER VIII

WEST INDIES

SECTION I.—THE WEST INDIAN ISLANDS

The West Indian Islands or Antilles⁷⁸ 89 103 119 121 122 124 147 149 156 166 169 175 181 188 189, considered as a whole, are situated on a composite steep curved fold or series of folds of the earth's crust, having a sunken area, the Caribbean Sea¹⁸¹, which forms a compound basin, on the inside of the concavity, thus resembling in plan the western Mediterranean ; it is likewise girdled by a chain of volcanoes. The western side of the Caribbean fold is much steeper than the eastern, so that westwards off Martinique depths of 1200 fathoms are met with at a distance of only 5 or 0 miles, while similar depths are not found for over 50 miles off the eastern side. The 2500-fathom slope passes east of the Bahamas, east of the Caribbean arc, and east of Trinidad and the Guianas, and only shallow passages connect the sunken areas with the Atlantic Ocean between Florida and Trinidad, except the Anegada Channel, which is a narrow trough over 2 miles deep, separating the Greater Antilles from the Windward Islands¹⁷ 85. The latter lie on three distinct elongated ridges, separated by deeps, projecting northward from the South American continent, and termed respectively the Barbadian, the Caribbean, and the Aves Ridges. The central or Caribbean is the longest and most important, extending northwards to the Anegada Channel, and rising considerably above sea-level in the true volcanic islands. The partly submerged mountain-chain which forms the whole compound arc practically separates the Atlantic Ocean from the Caribbean Sea and Gulf of Mexico. The crustal fold splits into two main branches in Haiti, one of them following a structural axis trending south-west through Jamaica, beyond which it is prolonged into Honduras as a submarine plateau, dotted with various banks and ' keys,' and thus dividing the Caribbean Sea into two parts ; the other or principal branch is continued as the dominating tectonic line north-west into Cuba, where apparently it divides again.⁵⁹.

Along the inner side of the arc in the Lesser Antilles⁴⁴ 78 119 155 is situated a line of active or dormant volcanoes, just as in the western Mediterranean the sunken area is girdled by a volcanic zone inside the folded zone. The chain of islands forming the Lesser Antilles is the only instance of an island festoon on the west side of the Atlantic resembling festoons in the Pacific⁷⁸ 119. The proximate

causes of the earthquakes and volcanic eruptions in the Caribbean area are probably to be sought in readjustments of the various folds or faults along which the rocks are in a state of constant strain. According to Taber⁸⁵ the east-west arcs delineating the major relief features of the Greater Antilles are zones of normal faulting which have developed in late geological time and have resulted in the formation of great troughs, of which the principal ones are (1) the *Bartlett Trough*^{171 172}, lying between Cuba and Jamaica and extending from the Island of Haiti westward into the Gulf of Honduras; (2) the *Brownson Trough*, lying immediately north of Porto Rico and the Virgin Islands; and (3) the *Anegada Trough*, which separates Porto Rico and the Virgin Islands Bank from St. Croix and the Lesser Antilles. The Bartlett Trough stretches for a distance of 1570 kilometres, and at its widest measures 150-160 kilometres across. Its deepest sounding, 3506 fathoms, is less than 50 km. from the coast of Cuba, and the six deepest places, all of which are over 3000 fathoms, are close to the enclosing scarps. The floor of the trough is relatively flat, and the trough is bounded by two fault zones which extend far beyond its limits. The Brownson Trough, which contains the deepest sounding made in the Atlantic Ocean, being over 4600 fathoms, is deepest at its west end, and is bounded on the south by a great scarp which rises steeply to the plateau-like ridge on which Porto Rico and the Virgin Islands are situated. The Anegada Trough is more or less transverse to the other two and is likewise bounded on the south by a steep scarp; its floor sinks to a depth of 2501 fathoms off St. Croix. 'The Antillean fault zones cut across the earlier trend-lines which seem to be due chiefly to folding and, because of their recency as well as the magnitude of the displacements, they dominate the present topography'⁸⁸. The main faulting probably took place in late Tertiary times⁸⁹, but the frequent occurrence of earthquakes shows that movements are still continuing. Dietrich¹⁸¹ has summarised the recent results of submarine soundings and their bearing on the structural relations of the Caribbean Islands.

According to Suess¹, the Antilles may be divided into several zones dependent on their geological structure and history. The first or innermost is the volcanic zone which comprises most of the Lesser Antilles and the Windward Islands, including the islands of Saba, St. Eustace, St. Kitts, Nevis, Redonda, Montserrat, the western part of Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent, the Grenadines, and Grenada. These islands form a continuous arc, and are almost entirely of recent volcanic origin, though most possess a foundation of older volcanic rocks³⁶. The second zone comprises the large mountainous islands of the Greater Antilles and lies outside the Lesser Antilles, though Ruten¹⁴⁹

maintains that both form part of the same arc. These islands possess a central core of ancient metamorphic rocks, rarely exposed, which Frazer⁸, Bergt, and others attribute to the Archaean or Palaeozoic². But the oldest fossiliferous rocks are of Cretaceous age, and in Jamaica even the metamorphic and igneous rocks¹⁴⁰ are assigned by Hill¹⁰ to the same period, but by Matley^{104 120} are held to be pre-Cretaceous. These are succeeded by a thick series of Tertiary deposits, of which some horizons have remarkable palæontological resemblances to those of the Mediterranean area¹⁵⁹. To this second zone belong the Great Antilles, including the islands of Cuba, Pinos, Haiti, Puerto Rico, the Virgins, St. Croix, Anguilla, St. Bartholomew, Antigua, the eastern part of Guadeloupe, and part of Barbados. Jamaica also belongs to this zone, but lies on the south-west branch of the main arc.

The third or outermost and eastern zone comprises only low islands and banks ; it is widest at its northern end, where it includes the Bahamas, but it narrows south-eastwards, where it is represented by the islands of Anegada, Sombrero, Barbuda, and part of Barbados.

The various land and sea connections¹⁴⁷ between the West Indies and Central America constitute a complicated history which has been interpreted in more than one way by Vaughan^{89 176}, Schuchert¹⁰³¹⁵⁶, Baker¹²¹, Bailey Willis¹²⁴, and Sonder¹⁶⁶. Rutten^{147 149}, who has recently given a summary of the different views on the subject, has criticised the theories of old land connections. The recent researches into the gravity anomalies¹⁵¹ in the Caribbean area have shown that the Lesser Antilles are situated on a geanticline and represent, according to Hess¹⁵¹, ' the structural connection between the Venezuelan chain and Greater Antilles,' as originally postulated by Suess¹ and held by Rutten¹⁴⁹. As regards a Tertiary connection¹⁴⁷ between North-West Africa, the Mediterranean, and America, including the West Indies, it has been contended¹⁶¹ that the geological history of the Atlas Mountains supports this view, as well as does the palæontological evidence^{162-165 188}. The biological and geological relations of the West Indies to Central America have been also discussed at length by Vaughan¹⁷⁶.

The islands of Trinidad and Tobago belong structurally to the South American continent, and are in intimate relation with the coastal Cordillera of Venezuela, so that their geological history is therefore distinct from that of the Antilles.

1. THE VOLCANIC ZONE^{160a-e}

The British islands are St. Kitts, Nevis, Montserrat, Redonda, Dominica, St. Lucia, St. Vincent, the Grenadines, and Grenada, and

they belong to a petrographical area characterised by the series of dacite-andesite lavas⁴⁴.

The Antillean region belongs as a **whole** petrographically to the **Pacific Province** of igneous rocks, the lavas being of a **sub-alkaline type**⁶⁴. The earlier eruptions took place in Miocene (Aquitanian) times, as proved by the fossils in the volcanic tuffs of Martinique.

St. Kitts^{94 160e} (St. Christopher's) shows a basement of older igneous rocks, breccias, agglomerates, and 'greenstones' (andesitic lavas). Such are exhibited in the Salt Ponds district and the south-eastern extension of the island⁹⁴. But the younger volcanic eruptions, which have covered up most of the older rocks, consist mainly of incoherent trachytic ashes with occasional boulders of trachyte. Only in one place has a basic lava (basalt)¹²⁵ been found *in situ*. The last eruption was in 1692. One peak on the volcanic ridge which forms most of the island, rising to a height of 4300 ft., has a crater on its summit.

On Brimstone Hill¹²⁵, a small volcanic dome 779 ft. high, there is found a white marl or limestone, the beds of which have been upheaved and fractured, and dip at high angles in every direction outwards from the centre. The rocks composing the hill are chiefly tuffs and hypersthene- and pyroxene-andesites¹²⁵ with a few limestones and marls, some apparently interbedded. Trechmann¹²⁵ believes that the extrusion of a volcanic plug has caused the disturbance of the sedimentary beds. The calcareous beds contain fossils (corals and mollusca), nearly all belonging to living marine species, and are believed to be late Pliocene or early Pleistocene in age, and to be equivalent to part of the Lafayette Formation of the American continent.

A coarse gravel formation composed of large rounded pebbles and angular material in horizontal strata is correlated with the Columbia Formation (Middle Pleistocene) of the American continent. The correlation, however, of all these West Indian Tertiaries is a matter of dispute^{59 75}.

The volcanic eruptions seem to have been at their maximum in early Pleistocene times, but have recurred since then at intervals till the end of the seventeenth century.

Montserrat^{148 152 160b} consists chiefly of volcanic materials. The island¹¹⁹ is 10½ miles long and 6 miles wide, and is composed of six adjacent volcanic masses each of which represents an old volcano¹¹⁹. In the southern part of the island the Soufriere Hills are the most recently active centre. These hills are regarded as large monolithic vertical extrusions of igneous rock, but active soufrieres occur in other parts. Marine limestones are associated with tuffs in steeply tilted and locally brecciated beds at Roche Bluff¹⁵² on the south-east coast, where the tuffs contain fossil corals and foraminifera not older than Miocene, and probably early Pleistocene. Seven distinct series of volcanic eruptions¹⁵² are traceable since late Miocene or early Pliocene times. MacGregor¹⁴⁸ is of the opinion that the submerged tectonic arc, on which Montserrat and other islands of the Lesser Antilles are built up by volcanic eruptions, dates back to the Laramide (early Eocene or late Cretaceous) orogeny. The rocks are described as trachytic, and soufrieres exhaling sulphuretted hydrogen are still active⁴.

Nevis^{94 160e} is a single volcanic mountain over 3500 ft. high, and possesses hot springs and fumaroles.

Redonda is likewise of volcanic origin, and is in a solfataric stage. It contains deposits of phosphate of alumina which occur in veins up to 2 ft. wide in the andesitic volcanic rocks⁶.

Dominica^{3 5107 119 160d} is the most mountainous of all the islands, and consists of a mass of volcanic ridges dissected by deep gorges; it measures about 34 by 15 miles in size, and is built up of Pleistocene and Recent deposits and volcanic rocks resting on a foundation of older igneous rocks. It has two volcanic centres, one in the north, Morne Diablotin, about 4700 ft. high, and the other in the south, La Grande Soufriere, over 3500 ft. high, with a great crater-like depression containing the famous Boiling Lake and many fumaroles⁶⁰. There are various other hot springs, soufrieres and crater-lakes in the island, and beds of sulphur and alum formed by them are known.

The basement of older igneous rocks consists chiefly of fragmental volcanic rocks, typically andesites, tuffs, and agglomerates. They are exposed south of Roseau and elsewhere round the coast, and probably are of pre-Tertiary age, according to Spencer.

The more recent lavas are trachytes.

An old series of volcanic tuffs of doubtful age, but probably Tertiary, has a wide development, and consists of beds as much as 10 ft. thick. Along the Roseau Valley there are beds of cream-coloured tuff of marine origin, with water-worn pebbles, which are apparently of more recent formation.

Two gravel formations, mutually separated by a great unconformity, are found on the island, and are younger than some of the Roseau tuffs. The lower or *Morne Daniel Series* extends from the foot of Morne Daniel in the sea-cliffs to a height of 300-500 ft. inland, and the beds undulate and dip in various directions to an extent of 15°-20° from the horizontal. Spencer refers them to the age of the Lafayette Formation.

In front of Grand Savanna¹⁰⁷ the upper or *Grand Savanna Series* of gravels is found, with a thickness of 30 ft.; it is compared with the Columbia Series of the American continent.

A whitish marl, 30 ft. thick, and raised 50 ft. above sea-level, and limestones, which are found in some valleys resting on the denuded Morne Daniel gravels, contain corals, mollusca, and echinoids, nearly all of Recent species, and, if correlated with the limestone of Brimstone *Bill*, St. Kitts, must be of earlier date than the upper series of gravels; its scattered fragments show its former wide distribution. In most cases the limestones and marls contain volcanic material, and subsequent lava-flows occur in places overlying the marine gravels and tuffs containing pockets of limestone. Recent volcanic activity, as above mentioned, is conspicuous in Dominica.

Terraces or old deformed plains, of which the highest, Morne Bruce, has an elevation of 400 ft., appear to be due to local uplifts of recent date.

St. Lucia^{5119 160c} consists mainly of a central dome rising to a height of 4000 ft., and formed chiefly of late volcanic accumulations. The northern part of the island consists of older igneous rocks of a doleritic nature, often decomposed to a depth of 20 ft. The well-known twin peaks on the south-west coast, known as the Pitons, are the central plugs of rhyolite or dacite in a dissected crater, as in Mont Pelee, and stand up out of a dissected plain of nearly horizontal beds of tuff. The volcanic activity of the island is only dormant, and there is a very active solfatara or fuming soufriere⁶⁰, with boiling springs and fumaroles, and many hot springs in other localities which deposit sulphur and other substances. The lavas of the island include hypersthene andesites.

St. Vincent^{44 160a} exhibits the old igneous basement in the south part of the island, where these basement rocks are weathered to a depth of many feet. Extensive beds of tuff, some with rounded pebbles, occur on the western coast. The Soufriere Mountain, which is a huge volcanic crater situated at the north

extremity of the island, measures over 4000 ft. high, and has a crater-lake at its summit in a pit nearly a mile in diameter, surrounded by vertical walls about 2000 ft. in height above the surface of the water⁹. An outer wall of an older crater encircles it, bearing the same relation to it as Monte Somma does to Mount Vesuvius. The first recorded eruption was in 1718 ; the great eruption of 1812 was nearly equalled by that of 1902^{8 9}. No true lavas appear to have been poured out at any time from this centre, the materials discharged always having been scoriae, ash, and boiling mud. The products of the 1902 eruption were found to be mostly a fine dark-coloured sand, and formed a layer of ashes 5-12 ft. deep, containing many spongy bombs of various sizes, and ejected blocks of the older rocks of the mountain. The commonest type of rock was andesitic in character, but some blocks of sanidine also were recognised. The fine dust which fell at Barbados on this occasion seemed to indicate by its constituents the presence of hypersthene-augite-andesites of a type common in the Andean and Mexican chains, and well known amongst the Recent volcanoes of the Pacific region.

The **Grenadines**⁵ are described by Spencer as 'merely the remnants of the erosion of old volcanic formations rising out of an extensive plain now submerged to between 100 and 200 ft.' Lavas with columnar structure have been observed on these small islands. The geology of one of them, Carriacou, has been recently described by Trechmann¹⁸, who shows that 'the island comprises a more or less conformable series of agglomerates, tuffs, shales, and limestones with occasional old lava-flows, these being overlain and capped in places by a covering of fresh-looking andesites and very fresh olivine-basalts. There is a broad band of a white bedded limestone (the Carriacou Limestone) extending nearly the whole length of the island and resting on old tuffs, agglomerates, and lavas. It contains *Lithothamnion* and foraminifera (*Amphistegina* and *Lepidocyclina*) with abundant mollusca, and is referred to the Upper Oligocene or Lower Miocene. Above it there are limestones containing species of *Pecten* and shales and sandstones with plant-remains. An unconformity separates this group from the overlying beds which comprise volcanic agglomerates, ashy shales, and tuffs, in which occur many gastropods and other fossils, the shales being referred to the Miocene and the overlying tuffs to the Lower Pliocene. Fresh andesites and olivine-basalts lie upon them, and are believed to be separated from them by an unconformity. The whole series of sedimentary beds is over 400 ft. thick.

Grenada^{138 160} has a rugged central mass of volcanic peaks. Le Morne Rouge is an extinct crater, and various crater-lakes and hot-springs point to dormant or recent volcanic activity. The volcanic materials of which it is composed are andesites and basalts of recent origin and include tuffs. Marine limestones of Pleistocene age occur up to 600 ft.¹⁸⁸,

2. THE CORDILLERAN ISLAND ZONE'

The fragmentary arc of which Jamaica forms part of the south-western branch, and to which also belong the British islands of Antigua, Anguilla, the Virgins, and part of Barbados, consists largely of folded Cretaceous and older rocks overlaid by thick Tertiary limestones, and by some other deposits of this period of different lithological character.

JAMAICA¹⁰⁻¹⁷ 65-70 73 70 76 81 83 84 86 99 104-106 112 113 120 123
130 132 133 140 143 158

This island, the largest of the British West Indies, has an area of about 4200 square miles, and stands almost in the middle of the * American Mediterranean.' It is separated from Cuba by a channel 90 miles wide and over 3000 fathoms deep, formed by a down-thrown faulted block (*Bartlett Trough*^{85 171 172}), and from Haiti by a sea 100 miles wide and 1000 fathoms deep, but is partly connected by projecting and overlapping submarine ridges. To the south there is a broad stretch of water with a depth of 2000 fathoms. To the west a continuation of its main axis is marked by submerged banks leading towards Honduras.

The principal old tectonic lines of Jamaica trend north-west to south-east, but other tectonic lines cross them nearly at right angles.

Physical Features^{10 17}.—The principal physical regions in the island are (1) the interior mountain ranges, constituting the nucleus ; (2) the elevated limestone plateau surrounding the nucleus ; (3) the coastal bluffs formed by the edges of this plateau ; and (4) the series of low flat coastal plains around the margin of the island between the coastal bluffs and the sea.

These regions are closely dependent on the geological structure. The interior mountain ranges include: (1) the Blue Mountains, which rise to a height of over 7000 ft., and extend from south-east to north-west for a third of the length of the island in a sinuous line parallel to the north-east coast but having many subsidiary branches; and (2) The Clarendon and Jerusalem Mountains farther west. All these are composed of much folded Cretaceous rocks, which are affected by two main lines of folding meeting *en echelon*. There is an older pre-Cretaceous basal complex^{104 120} underlying these rocks east of Kingston.

The plateau region, rising to a height of 3000 ft., and now forming a much dissected plain, occupies fully four-fifths of the whole area of the island, and is composed of soluble Tertiary limestones more or less horizontal and weathered into 'cock-pits,' swallow-holes, basin-valleys, and deep gorges. A typical 'karst' landscape⁸³ has been developed in this area.

The coastal bluffs are of special geological interest because they show several ancient terraces, sea-levels or 'benches,' at heights of 2100 ft., 1500 ft., 1000 ft., 600 ft., 300 ft., and 200 ft.

The coastal plains, which are mostly narrow, consist of elevated reefs, sea-beaches, and littoral deposits, with raised terraces and marginal plains representing old levels of erosion such as that on which Kingston stands. All these formations are of late Tertiary or Quaternary age.

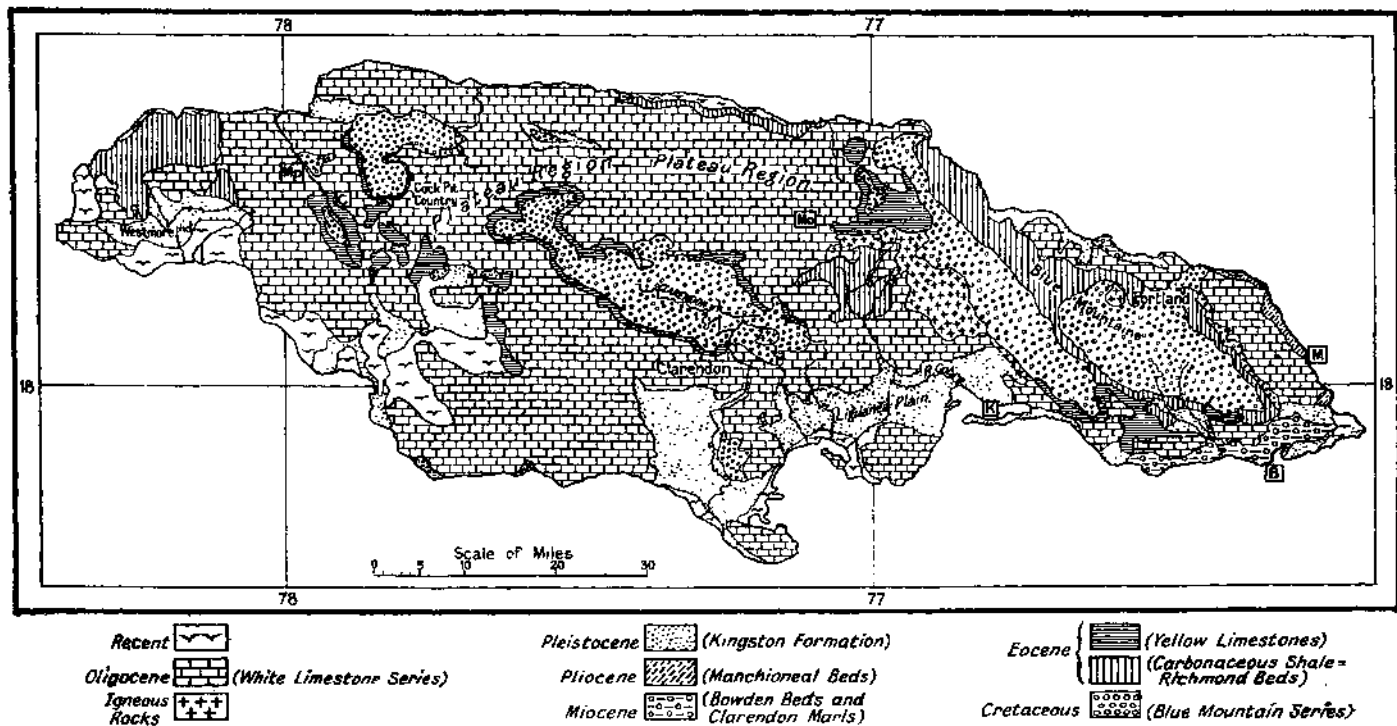
Geology.—There has been a considerable diversity of opinion regarding the classification and age of the rocks forming the island, and R. T. Hill's⁴⁰ generally accepted division into four series can no longer be maintained. The pre-Cretaceous, Cretaceous, and some Eocene beds were included in Hill's 'Blue Mountain Series' and 'Igneous Series,' while the great mass of Tertiary limestones (mainly Eocene and Oligocene) corresponds nearly to his 'Oceanic Series'; finally his 'Coastal Series' comprises Miocene, Pliocene, and post-Pliocene deposits. Trechmann's classification and nomenclature⁶⁶ of the Cretaceous and Tertiary rocks are here adopted, except as regards the age of the schists, marbles, gneiss, and granodiorite which Matley^{164 120} holds to be pre-Cretaceous and to constitute a basement series; Trechmann¹⁴⁰ denies that there is any evidence of such an age or foundation, thereby agreeing with Hill's previous opinion¹⁰.

(1) **The Basal Complex**¹⁴⁰ (=the metamorphosed series of Sawkins). Matley^{104 120} has described the varied assemblage of rocks which formed the basement on which the Cretaceous and late beds were deposited. It consists of various metamorphosed sediments (schists, marbles, etc.) and igneous rocks, including lavas, volcanic fragmental rocks, and intrusives, the widespread granodiorite¹²⁰ being amongst the later intrusions. The sediments may be partly of Palaeozoic or of earlier or later date, but are unfossiliferous. The reddish andesitic lavas and tuffs with associated intrusives in the Kingston district are, however, considered by Matley¹²³ to be of Cretaceous age, but there is a difference of opinion¹³² as to the age of these igneous rocks, some of which may be post-Cretaceous. Thus Trechmann¹⁴⁰ holds that the serpentine intrusions near Trout Hall may be Cretaceous in age, but that the large granodiorite-porphry batholith is intruded into Cretaceous and Tertiary beds as high up as the White Limestone (Oligocene or Lower Miocene) and is therefore one of the latest intrusives, and does not form part of a Basement group of rocks such as Matley¹²⁰ maintains.

Cretaceous (*Blue Mountain Series*).—This system is represented largely by limestones with associated shales and sandstones and conglomerates¹⁴⁰. Trechmann⁶⁶ has specially studied the succession and faunas^{70 99 106 185}. The rudistids⁸⁴ are the most important members of the latter. All the beds are referred to the Upper Cretaceous (Senonian to Maestrichtian^{67 86}), but the precise sequence is undetermined. The beds form much of the Blue Mountains, and even have yielded fossils on Blue Mountain Peak at over 7000 ft.¹⁰⁶. The Cretaceous limestones⁷⁰ contain amongst the rudistids very large species of *Radiolites*⁸⁴ and *Barrettia*⁶⁷ with other genera, as well as gastropods (*Actæonella*, etc.) and ammonites *Parapachydiscus*, *Glyptoxoceras*, *Baculites*, etc.⁸⁶, together with corals^{126 141 185}. The peculiar genus *Barrettia* is also found in Cretaceous beds in St. Croix and Guatemala. The fauna recalls that of the Gosau beds of the Eastern Alps, and the same type of Upper Cretaceous fauna has been recognized in St. Thomas, Cuba, Porto Rico, and probably Haiti. The Blue Mountain or purple conglomerate, which is associated with marine Cretaceous shales and limestones, includes a few pebbles of granite and more of limestone, some of which contain foraminifera¹⁵⁷ (*Textularia*, etc.), echinoderm plates and spines, and many fragments of *Lithiothamnion*, a genus which occurs from the Aptian upwards¹⁴⁰. Associated closely with the rudistid limestones, and stated "to occur both above and below them, are the *Cretaceous Shales*⁹⁹, containing an abundant fauna of mollusca almost entirely different from that in the limestones.

In the neighbourhood of Kingston, Matley¹²³ recognises a group of red, purple, and brown sandstones, flags and mudstones, with some limestones and vesicular basic and spilitic lavas and tuffs and associated thick masses of gypsum, resting on red andesites and tuffs of Cretaceous age. These beds may be of Eocene rather than Cretaceous age, and may be passage beds leading up into the true Eocene (Richmond beds), but there is no genuine mingling of the Cretaceous and Tertiary faunas as has been often stated, the admixture of fossils being due to derivation owing to the erosion of the earlier Cretaceous beds before the deposition of the Tertiary, as Trechmann⁶⁹ has shown (see below).

Eocene.—The formation which was termed by Hill¹¹⁰ the *Richmond Formation* and was correlated by Vaughan^{59 75} with the Upper Eocene limestones of St. Bartholomew and the Jackson Formation of the Gulf States and Venezuela^{124*} is termed by Trechmann^{66 69} the *Carbonaceous Shale*, for it consists of black bituminous and flysch-like shales and brockram-like conglomerates¹⁴⁰ with derived Cretaceous and fresh or slightly rolled Eocene fossils,



REFERENCES.—B. Bowden ; C. Cambridge ; K. Kingston; M. Manchioneal; Mo. Moneague ; Mp. Montpelier.

FIG. 12.—GEOLOGICAL MAP OF JAMAICA (based on Hill's Map).

- EXPLANATION
- I. Inner or Volcanic Zone.
 II. Middle or Main Caribbean
 Zone of folded Cretaceous
 and Tertiary Rocks.
 III. Outer Zone of low-lying
 coral islands.

REFERENCES

- A. Antigua.
 Al. Anguilla.
 An. Anegada.
 B. Barbuda.
 Bs. Barbados.
 B.H. British Honduras.
 Ca. Caicos Is.
 D. Dominica.
 G.B.B. Great Bahama Bank.
 Gr. Grenada.
 Gs. Grenadines.
 Gu. Guadeloupe.
 G.C. Grand Cayman.
 J. Jamaica.
 L.C. Little Cayman.
 M. Montserrat.
 Ma. Martinique.
 M.B. Mosquito Bank.
 N. Nevis.
 P.B. Pedro Bank.
 P.R. Porto Rico.
 R. Redonda.
 R.B. Rosalind Bank.
 S. Saba.
 So. Sombbrero.
 S.B. St. Bartholomew.
 S.C. St. Croix.
 S.K. St. Kitts.
 S.L. St. Lucia.
 S.V. St. Vincent.
 T. Tortola.
 To. Tobago.
 Tr. Trinidad.

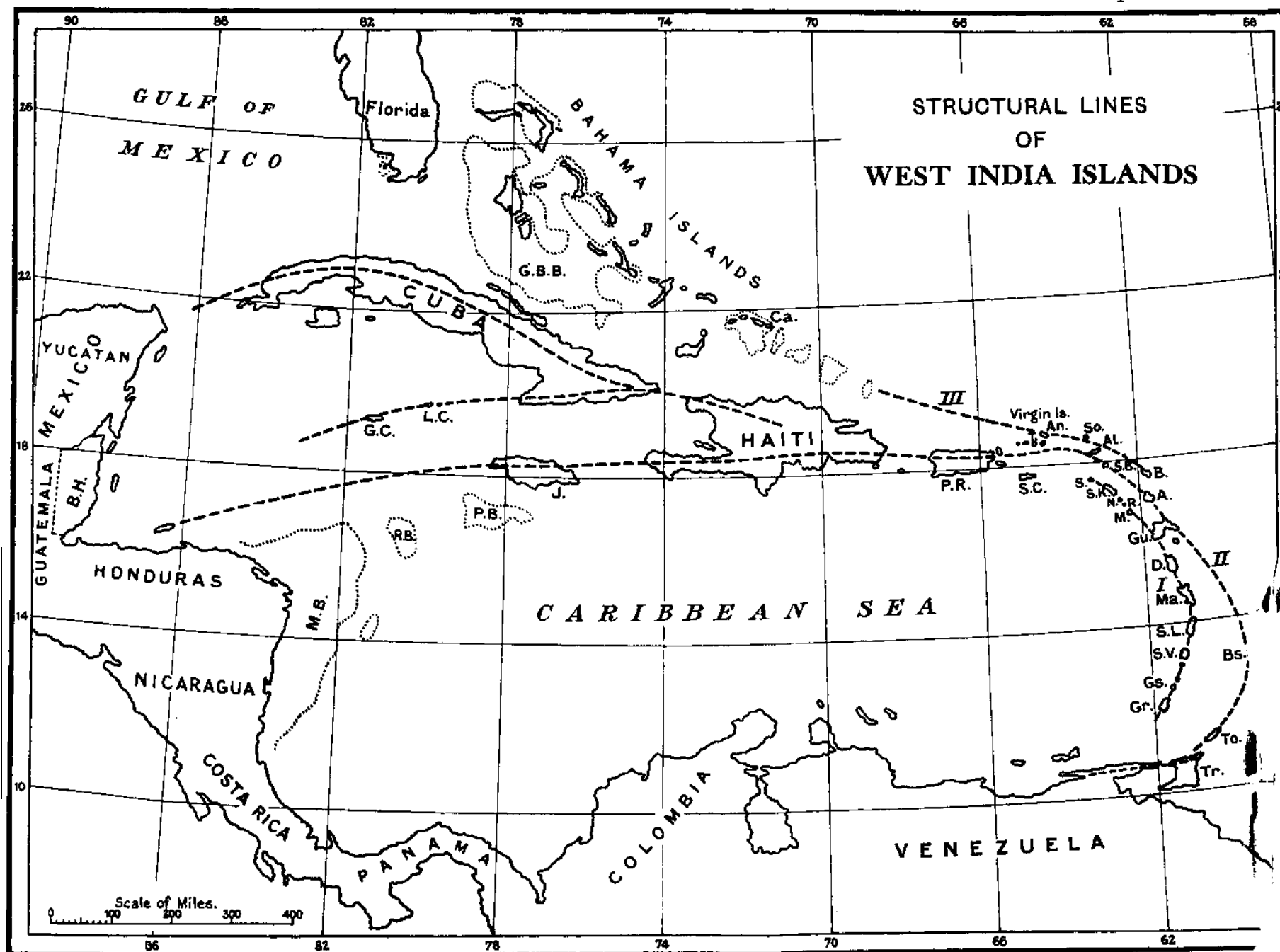


FIG. 13

including *Velates* and many other genera of gastropods⁶⁹ and some corals¹²⁶. It is doubtful if this formation is older than the "Yellow Limestone," but the latter is said to rest on the Carbonaceous Shale with a local unconformity. Probably the two formations differ more in lithological characters than in age. Trechmann¹⁴⁰ states that the conglomerates associated with the Richmond beds or Carbonaceous shale 'yield rolled Cretaceous Rudists, etc., together with Eocene marine and freshwater mollusca, and include pebbles of gneiss, schist, granite, porphyry, lavas, agate, quartz, etc.', which suggest the neighbouring presence of an ancient land-mass¹. Since in south Mexico Cenomanian beds have been altered into gneisses and schists, Trechmann questions whether these pebbles can be held to prove an Archæan or Palæozoic basement in Jamaica such as Matley maintains. The *Yellow Limestone*⁶⁸ mostly rests on the pre-Cretaceous basement complex or Trappean beds⁶⁸, and its relation to the Richmond beds is doubtful. It is exposed in central and western Jamaica, is about 400 ft. thick, and consists of massive or marly yellow limestones with some shales and lignite-bands. In the lower part the gastropod *Velates schmideliana* Chemn. is characteristic, and in the upper part *Carolia jamaicensis* Dall and many gastropods, lamellibranchs, echinoids^{76 112 173 182} and corals^{113 126 185} occur, while some beds are full of foraminifera¹³³ (*Operculina*) and other bods of *Alveolina* or *Orthophragmina*. The Yellow Limestone is referred to the Middle Eocene.

Oligocene.—The *White Limestone* formation, which overlies the Yellow Limestone and is also called the Cockpit Limestone (from its development in the Cockpit area of Jamaica), is a hard massive rock for the most part, but includes, according to Trechmann's usage of the term, the Moneague and Montpelier beds of *Kill*¹⁰ which are foraminiferal chalky limestones with bands of flint. The Montpelier Formation seems to be a deep-water facies of the White Limestone, and contains *Orbitoides mantelli*, while the Moneague Formation includes the *Lepidocyclina undosa* zone. The base of the White Limestone is a variable horizon, the bed sometimes passing down conformably into the Yellow Limestone; it is considered that the White Limestone ranges from Upper Eocene to Upper Oligocene or Miocene¹⁵⁸. The White Limestone occupies about half the surface of Jamaica, and has a total thickness of about 2000 ft. It is characterised by foraminifera^{133 158}, which allow of its division into zones, but corals¹¹³, echinoids^{76 77 112 122a 173}, and other groups¹³⁰ are also well represented in it. It may be mentioned that *Orbitoides mantelli* is a characteristic fossil of the Vicksburg beds of America⁵⁹ and of the Oligocene of Malta^{147 164 165 168}. The remarkable similarity or affinity of elements in some Tertiary marine faunas^{164 165 168} of the Mediterranean and West Indian and Central American regions has often been noticed and made the basis for the theory that land-bridges or a chain of islands stretched across the mid-Atlantic during part of that period^{147 161-165 168 169}.

Miocene.—The *Bowden beds*^{11 19 113}, consisting of marls, gravels, and shell beds on the south-east of the island at Bowden and Port Morant, which are now referred to the Middle Miocene, have yielded a rich fauna of corals, bryozoa, echinoids^{76 77 182}, and especially mollusca^{13 19 59 73 73a}. These beds are separated by an unconformity from the White Limestone, the island having been uplifted and the White Limestone disturbed and crushed before their deposition. The same horizon and fauna are represented in Cuba, San Domingo, and Costa Rica. Matley¹²³ has described a series of highly-fossiliferous Upper Miocene beds between Long and Dallas Mountains, lying unconformably on the White Limestone and containing some beds full of *sphærogypsina*. The series is there overlain unconformably by the Liguanea Formation.

Pliocene.—The *Manchioneal beds*¹⁰⁵ probably belong to the Pliocene rather than to the Miocene, though the corals and mollusca¹⁶⁴ show more affinity with those of the Bowden beds than with the living marine fauna. They occur chiefly round the eastern end of the island and consist mainly of clays and limestones with a meagre fauna. They immediately underlie the Recent coral rock or coastal limestones.

Plio-Pleistocene.—The *Kingston* (or *Liguanea*)¹⁷ Formation is another type of deposit, and consists of gravels and alluvium, in places reaching a thickness of 1000 ft. ; it forms the Liguanea Plain, and extends up to all altitudes less than 600 ft. It is partly a talus and partly an estuarine deposit or marine delta, and may possibly have accumulated through several geological epochs. Fossils are generally wanting.

Of later date, partly Pleistocene and partly Recent, are the elevated coral reefs which border the coast, and constitute horizontal beds of reef-rock, 10-40 ft. thick, and indurated to a varied extent^{10 59}. Three distinct levels at heights respectively of 70, 25, and 10 ft., are recognised ; and contemporaneously with the formation of these reefs chalky white marls or limestones accumulated in the adjoining sea ; such occur on the coast of Trelawney, Hanover, and Westmoreland. The so-called 'cays' of Jamaica¹⁴⁸ are small islets of recent origin consisting merely of irregular masses of sand and coral-rock with coarse fragments of corals and broken shells washed up by the waves into heaps on coral reefs and on partly submerged shoals, the materials being more or less cemented into 'beach rock.' Calcareous algae, especially *Halimeda*, play an important part in their formation, and the vegetation which springs up on them rapidly helps to consolidate the material and convert them into more or less permanent islets.

Igneous Rocks of Tertiary Age.—The Low Layton volcanic rocks are possibly of Oligocene age and contain many 'pillows' of highly vesicular lavas (basalts). The latest intrusions¹³² (laccolites, dykes, and sills), some of which are stated to invade the Montpelier beds, appear to be of Upper Eocene age. The great porphyry sill¹²³, which is over 1000 ft. thick and is known as the Newcastle sill, occupies a large belt of country west of the River Yallah and has invaded Lower Eocene beds.

CAYMAN ISLANDS

The Cayman Islands⁷⁴, all of which are low-lying, seem to lie on the westerly prolongation of the Sierra Maestra in the south-east of Cuba, a range which strikes in this direction to the Gulf of Honduras⁵⁹, forming the submarine Cayman Ridge along the axis of which these islands rise above sea-level. The largest of the three islands is the Grand Cayman, 17 miles long and 2-7 miles broad, but the highest land in the group is on Cayman Brac, where the median rocky ridge rises to 150 ft. at its east end. On the south of this ridge^{74 85} the Bartlett trough^{85 171 172} descends to over 3000 fathoms within 18 miles of the Grand Cayman. Each island is a separate faulted block⁷⁴, and consists of calcareous rocks. The older formation, termed the *Bluff Limestone*, is correlated with part of the White Limestone (Oligocene) of Jamaica, and contains *Lepidocyclus undosa* Cushman and *L. gigas* Cushman¹⁰⁰. It forms a flat platform of waterless karst-land in each island. The younger formation, termed the *Ironshore Formation*, constitutes the coastal platform rising inland 12-15 ft. above tide-level; it is of post-Pliocene or Pleistocene age, and contains mollusca and corals of living species⁷⁴. It may be correlated according to Matley with the so-called Falmouth Formation of Hill¹⁰ in Jamaica; a similar marine terrace is widely developed on the coasts of tropical America.

VIRGIN ISLANDS

The Virgin Islands²⁸⁰ are situated on the main arc of the Cordillera at the east end of Puerto Rico, and are separated from St. Croix by a down-thrown faulted block. They are entirely composed of igneous or metamorphic rocks, with no signs of unaltered sedimentary beds. The igneous rocks^{80 93} include plutonic, hypabyssal, and volcanic types; diorites, granodiorites, and gabbros occur amongst the first, pegmatites, felsites, hornblende-porphyrites, and dolerites amongst the second type, while the volcanic type comprises augite-andesites and basalts. The metamorphic rocks are mostly altered sedimentaries and include hornblende-, mica-, and quartz-schists, phyllites, and spotted schists, marbles, garnet-wollastonite rocks, granulites, etc.; they are often interbedded with the volcanic breccias and agglomerates. From the occurrence of Cretaceous fossils in similar but less altered beds on St. Thomas, their age is presumed by Earle⁸⁰ to be the same. Numerous quartz-veins and dykes of felsite and pegmatite traverse the metamorphic rocks.

The general strike of the rocks is from east to west, and they are said to dip at high angles to the south or to be vertical. Vaughan⁹³ considers that the folding of the rocks took place between Upper Eocene and Middle Oligocene times, and that the diorites were intruded at approximately the same time. But the latter may be earlier. The volcanic rocks are undoubtedly of Tertiary age. Lava-flows are rare; the agglomerates are full of andesitic bombs, and the tuffs belong to the same period of eruption. The dykes of hornblende-porphyrite, etc., cut the plutonic and metamorphic rocks, and probably represent the last phase of igneous activity in the area⁸⁰. In Tortola, which is the largest of the group, the igneous and metamorphic rocks form a high mountainous ridge running the whole length of the island; the beds are all much disturbed and have very high dips.

The neighbouring islets appear to consist partly of diorite, but on *Virgin Gorda* felsite occurs in the northern part, quartzite or altered sandstone in the middle part, and diorite with fine spheroidal structure in the south. Native copper and other ores are stated to occur in the latter district.

The small islets known as Ginger Island, Cooper's Island, and Salt Island contain a variety of rocks, including amphibolite and micaceous schists (as in Cuba and Haiti), diorite, and intrusive dykes of diabase and granite; some of the rocks apparently represent the Basement series of Jamaica.

ANTIGUA⁴ 62 63 119 129150

This island, which has an area of about 108 sq. miles, is occupied in its central portion by plains, but a mountainous belt, which rises in places to a height of over 1300 ft., forms the south-west region, and an undulating belt, with hills of a height up to 250 to 400 ft., constitutes the north-east portion. These three topographical regions owe their position and features directly to the geological structure of the island. The southernmost or mountainous zone is composed of igneous rocks supposed to be the oldest rocks in the island⁴⁴. They include massive flows of pyroxene andesites and basalts (with much olivine), but chiefly consist of beds of agglomerate and ash dipping north-eastward. The whole series may correspond partly to the Basement Series of Jamaica. Cushman¹⁸⁴ has recognised Cretaceous foraminifera in these beds, but there is considerable doubt as to whether the specimens really came from Antigua¹²⁹. Resting on the beds at a few points is a dark, compact, fossiliferous limestone, dipping at considerable angles south-westward, and known as the *Seaforth Limestone*^{62 120 181} it is completely different in

character from the other limestones ; according to Trechmann¹²⁹, it is 50-60 ft. thick and forms part of a small isolated hill. It rests in one place on a conglomerate and in another place on calcareous tuffs and contains species of foraminifera, including *Lepidocyclus* (*Eulepidina*) *favosa* Cushman and *L. (E.) undosa* Cushman, which indicate a Middle Oligocene age. A species of *Orthaulax*¹²² has also been recognised, and Thomas¹³¹ has described other fossils, chiefly corals, which support this correlation.

Considerable denudation of the Basement rocks occurred before the deposition of the main mass of Tertiary beds. The latter commence with a series of stratified tuffs and shales, containing lenticular masses of cherty limestone in which are rounded or fragmentary corals. These beds occupy the central plain. The tuffs appear to have been derived from the denudation of the older volcanics, and to be of sub-aqueous origin; but there is some evidence of local contemporaneous volcanic activity in the shape of pyroxene andesites. Some of the igneous activity is now known to be of late Tertiary age. The trachydolerite of Drews Hill¹²⁰ which forms a saddle-like ridge from north-west to south-east seems to be a laccolitic intrusion in Hill's 'Oceanic Series,' a formation of late Tertiary age. Vaughan⁹³ records dacites, basalts, andesites, and their tuffs, some of which are older and others younger than the Antigua limestone (see below). In the associated marine limestones occurs the fossil *Orbitoides mantelli* characteristic of the Vicksburg Stage of the southern United States, and occurring also in the Montpelier beds of Jamaica, as previously stated¹⁰. Corals are especially abundant in these beds, and many were described by Duncan¹⁹ in 1863. It is probable⁵⁹ that some of the beds are of Upper Eocene age, as suggested by a fossil fish found in a bed stratigraphically below the limestone.

The whole of these marine Tertiary deposits dip north-eastward at angles from 12° to 20°, and form the central plains. Above them come volcanic sands and grits and thin layers of chert containing silicified wood and fresh-water shells, and these beds pass up without a break into the overlying White Limestone.

The north-eastern or undulating hilly portion of the island is composed of the upper part of the same group of Tertiary deposits, but the beds here consist of a series of earthy marls and compact limestones many hundred feet thick. It is known as the *White Limestone* or *Antigua Formation*, and succeeds conformably the underlying beds, having also the same dip. The beds are highly fossiliferous, yielding many small corals¹⁹ (often silicified), calcareous algae¹⁴⁴, mollusca, and some echinoids, which are closely allied to, or identical with, Maltese forms, and include the genera: *Clypeaster*, *Echinanthus*, *Sismondia*, *Schizaster*, and *Echinolampas*⁷⁷.

The limestone is largely composed of specimens of *Orbitoides* (*O. mantelli*), though in places it consists of masses of corals¹³¹. Vaughan⁵⁹ considers that the corals and algae¹⁴⁴ indicate a Middle Oligocene age for the Antigua Formation, and that the same coral fauna occurs in Porto Rico, Cuba, southern Georgia, etc. It is correlated with the Rupelian of Europe.

At Crosbie's Mill near the north coast of the island the White Limestone is invaded by a small dyke of black olivine-basalt, thus affording further evidence of late Tertiary igneous activity. The fresh-water shelly marls north of Fort James, which are almost completely silicified and alternate with bedded clays and conglomerates, contain gastropods of the genus *Hemisinus*¹²⁹, and are referred to the Miocene. But Pilsbry¹⁹⁴ described others from the Oligocene.

Resting on the eroded surface of the White Limestone is an extensive series of marls and gravels composed of limestone pebbles. The bedding is horizontal, and the deposit, which is known as the *Friar's Hill Series*, extends up

to a height of 200 ft. Its precise age is uncertain, for it is unfossiliferous, but it is stated by Spencer⁴ to have the same characters and relations to the underlying beds as that part of the Coastal Series in Jamaica known as the Man-chioneal beds.

A later set of gravels, composed of water-worn pebbles of igneous rocks, interstratified with loam, is about 20 ft. in total thickness, and forms a series of mounds near St. John's. It has been called the *Cassada Garden Gravels*, and resembles the Columbia Formation of the American continent, the Zapata of Cuba and the Kingston or Liguanea of Jamaica.

Spread over the central plain there are also extensive shell beds, all the shells of which belong to Recent species; they must have been formed when the island stood at least 150 feet lower than it does at the present time. Horizontal deposits of marl occur also along part of the northern coast of the island at a height of 10-12 ft. above sea-level, containing marine and land shells, some of the latter belonging to extinct species. According to Davis⁷⁸ Antigua and Barbuda should be regarded as parts of a tilted and partly re-levelled atoll which has suffered more than one upward and downward movement.

ANGUILLA

Anguilla^{93,94}, lying farther to the north, has a basement of old eruptive rocks (greenstones or dioritic porphyry⁹³ and andesitic tuffs). A calcareous volcanic and cherty series, like certain beds on St. Bartholomew which have been assigned to the Middle Eocene, appears also to be present. Some detailed sections have been given by Vaughan⁹³.

Limestones rest unconformably on these older formations; the lower of these beds contain many echinoids⁷⁷, mollusca, algae¹⁴⁴, and fish¹¹. Some of the echinoids⁷⁷ occur in the Oligocene of Malta, as in Antigua, and other species are closely allied; such are *Schizaster scillæ* Desm. and *Cidaris melitensis* Forbes, and some species of *Echinolampas* and *Clypeaster*. Vaughan^{59, 77} regarded this Anguilla Formation to be younger than the Antigua Formation, and refers it to the Upper Oligocene (=Aquitanian), correlating it with the Tampa Formation of Florida and with certain limestones in Panama, but more recently⁷⁵ with the Langhian⁹³. The typical Tertiary gastropod *Orthaulax*¹²² occurs in these beds in Anguilla as well as in Antigua. The upper beds, which rest unconformably on the lower, contain living species of corals, and are probably of Pliocene age. Representatives of the later gravel-deposits of Antigua have also been recognised on the island.

In the caves of Anguilla (and St. Martin) are found the remains of large South American rodents (*Amblyrhiza*, etc.), pointing to a late connection of these islands with the South American Continent^{121 124 147 168} (see below, p. 275).

BARBADOS 21-25 71 109 117 145 190

This island is the most easterly of the West Indies, and partly belongs to the Cordilleran zone, and partly to the outermost zone¹⁰⁹. It measures about 21 miles long by 11 miles broad, and is traversed by a central curved ridge rising to heights of 1000-1100 ft. South of this ridge lies a broad depression, forming the Scotland district, and bounded on the south by a lower ridge not over 400 ft. high, which runs nearly due east and west, and sinks down in a series of slopes and terraces.

Stratigraphy.—The rocks which enter into the structure of the island are

now classified as follows in descending order, all subdivisions being separated by unconformities:—

4. Coral Limestones.
3. Oceanic Series.
2. Joe's River Clay.
1. Scotland Beds.

There are no volcanic rocks, except fine volcanic dust and sand, and six-sevenths of the surface are covered by the coral limestones, but there is evidence of an old basement of igneous and metamorphic rocks¹¹⁷.

(1) The **Scotland Beds**⁷¹ form the core of the island, and consist of coarse grits, brownish sands, dark sandy and mottled clays, which are in places saturated with petroleum, and contain lenticular beds of asphalt. These old beds have been much folded along axes striking mostly E.N.E.-W.S.W. and are broken by many faults; their base is not seen, so that their true thickness is unknown, but 500-600 ft. of them are exposed. Their Eocene age is now settled. They yield a few species of mollusca, some of which occur in the San Fernando and Naparima marls of Trinidad²⁶, and in the corresponding beds of St. Bartholomew, which are now generally referred to the Lower or Middle Tertiary. The general facies of the fauna is Eocene or Lower Oligocene, and shells allied to *Clarella longæua*, *Nerita aperta*, *Potamides funatus*, and *Pleurotoma transversaria* have been recognised. Gregory and Heilprin refer them to the Oligocene, but Wells¹²⁶ considers that the corals indicate Lower Miocene. Trechmann⁷¹ has recently re-described the whole series of the Scotland Beds and the fauna in them, and has concluded that there is a considerable affinity with the Claiborne facies of Alabama, the Eocene of Ameki, Nigeria, and the Lutetian and Bartonian of Europe. It seems that the beds may best be referred to the Middle or Upper Eocene, and possibly more than one horizon is represented. Beeby Thompson¹⁷⁰ has separated off a lower group consisting of sandstones and grits, several thousand feet thick, with a thick sandy shale below the upper sandstones. His upper group of the beds, which have a conglomerate at their base followed by sandy beds and clays, contains nearly all the fossils, amongst which is *Nummulites variolarius*, an Upper Eocene species¹¹⁷. These Scotland beds were strongly folded and even overthrust before the succeeding beds were laid down on them. We may note that the composition of the beds in the Scotland Series indicates that the materials were derived from a Basement Series of rocks like those in Trinidad and Venezuela. Senn¹⁹⁰ divides up the *Scotland Beds* into a lower and an upper group, each consisting of a series of beds with slightly different fossils, and lithological characters; the lower group consists chiefly of shales and the upper group of sands. The age of the whole series is put by him as Middle Eocene and correlated with the Point a Pierre beds of Trinidad.

Between the Scotland Beds and the so-called Oceanic Series¹¹⁷ (which does not correspond to that similarly named by Hill in Jamaica) there has been recently recognised¹⁷⁰ a formation termed the '*Joe's River Clay*,' a few hundred feet thick, consisting of a black oil-soaked clay containing large fragments of sandstone saturated with heavy oil. Senn¹⁹⁰ terms these beds the '*Joe's River Beds*,' and describes them as pebbly silts and tar sands with enclosed masses of clay; he regards them as mud-flows resulting from the activity of mud volcanoes. These beds are the great oil-bearing series of the island, and manjak also occurs in the fissures of the strata, often in large masses.

The **Oceanic Series**²⁸, which was referred to the Miocene⁶⁹, but is now assigned to the Upper Eocene¹⁹⁰, rests¹⁴² on the eroded and upturned edges of the folded Scotland Beds and Joe's River Clay, and is chiefly exposed in the

south-west part of the island along the coast. It consists of several hundred feet of fine white earths, some calcareous and others siliceous, with subordinate beds of pink and yellow clay and layers of grey pumiceous volcanic sand. The whole series is most completely developed on Mount Hillaby, where it is 620 ft. thick, and is divisible into five stages or phases which blend into each other. The first phase consists mainly of white or cream-coloured earthy limestones, some soft and some hard. These are full of *Globigerina* and other oceanic foraminifera, etc., and contain 60-80 per cent, of carbonate of lime. The second and central part of the series comprises the well-known *Radiolarian* or *Infusorial Earths*^{22 23}, which are white, yellowish, or drab in colour, and are almost entirely composed of radiolarian tests, diatoms, and sponge-spicules⁵⁵. Associated with them are some layers of felspathic and pumiceous sand or dust. Next comes a second band of calcareous deposits similar in character to those of the first phase. Then follows a mass of very fine argillaceous earth, red, pink, white, or mottled in colour, and apparently analogous to the modern 'red clay' of the deep seas. It never contains more than a trace of carbonate of lime, but yields a few radiolaria and sponge-spicules. On Mount Hillaby these beds are succeeded by 25 ft. of grey mudstones or felspathic earths composed mainly of fine volcanic dust.

The Oceanic Series rests with a strong angular unconformity¹⁹⁰ on the older beds and is referred by Senn to the Upper Eocene and compared with the Hantkenina marls of Hospital Hill, San Fernando, Trinidad; its deep-water character suggests that it is the predecessor of the Brownson trough.

The calcareous and caleareo-siliceous earths- have been frequently compared to parts of the Chalk of England in respect of their composition and origin, but the Barbados deposit differs in several particulars, (a) by an absence of fragments of shells of mollusca and echinoderms, (b) by the presence of recognisable radiolarian remains, (c) by the greater thickness of the cell-walls of the foraminifera, (d) by the size and abundance of the coccoliths and crystalloids, and (e) by the presence of angular mineral chips and grains. The depth of water indicated by the fauna contained in this deposit is between 500 and 1000 fathoms; from the foraminifera the age of these beds has been regarded as late Pliocene, 93 per cent, of the species of foraminifera being living forms.

The *radiolarian oozes*⁵⁵ have yielded a species of *Cystechinus*^{109 117}, a living echinoid genus which is never found above the 1000-fathom line, and the testimony of the radiolaria themselves is compatible with depths of 3000-4000 fathoms. A probably Pliocene age for the beds has been deduced from the evidence of these organisms, but, as stated, Senn¹⁹⁰ puts the Oceanic Series in the Upper Eocene.

The coloured argillaceous earths bear a great resemblance to the red clays of the Atlantic obtained from depths of 2700 fathoms, and the layers of volcanic dust resemble in character and composition the material thrown out from La Soufriere in St. Vincent in 1812 and deposited on the surface of Barbados.

In Haiti, Cuba, and Trinidad there occur beds which are similar in character and relative position to this Oceanic Series of Barbados.

In the north of the island at *Bissex Hill*^{21 109 145} a series of marls, known as the *Globigerina Beds*, overlies the Oceanic Series unconformably, and is thought to be intermediate in age between the latter and the Coral Limestones up into which they pass. Compact limestones occur in the upper part containing the echinoid *Archæopneustes abruptus*, the gastropod *Scalaria ehrenbergi*, turbinate corals, etc., and here and there throughout the beds there are sharks' teeth (*Carcharodon*, *Lamna*, *Oxyrhina*, etc.) in abundance. The total thickness of the *Globigerina Beds* on Bissex Hill is about 90 ft., and that of the succeeding passage beds not more than 20 ft. Spencer assigned the immediately

overlying coral limestones to the Lower Miocene, making the Globigerina beds of Oligocene age, but some authors refer these Globigerina beds as well as the coral limestones to the Pliocene and Pleistocene. Senn¹⁹⁰ refers the Bissex Hill Marls to the Upper Oligocene or Lower Miocene.

The **Coral Limestones**^{109 145} usually rest unconformably on the Oceanic Series, but in places on the older Scotland Beds, and they cover six-sevenths of the island. An older and a newer series are distinguishable amongst them, the former covering the higher parts of the island and dipping at 15°-20° to the south-east. The older limestones are said to show evidence of having suffered enormous erosion before the newer series of coral limestones was laid down on them unconformably and horizontally. Two divisions of these newer limestones have also been recognised, of which the older division is composed of mechanically formed limestones and marls, being detrital in origin, while the newer division is of true coral formation. Still later coral reefs and coral deposits bring us down to Recent times. A large number of mollusca^{109 145} and corals²⁴ have been obtained from these limestones. The age of the various divisions of the coral limestones is a matter of much dispute, and very diverse views are held, Spencer⁵ correlating the older series with the White Limestone (Oligocene or Miocene) of Antigua, while other authors would attribute all of them to the Pliocene or Pleistocene^{24 145}. Vaughan⁵⁹, for instance, doubts if any of the elevated terraced coral reefs of Barbados are as old as the Pliocene, for practically all the coral species are inseparable from those now living in the Caribbean area. According to Trechmann¹⁴⁵ 'the coral-rock commences nearly everywhere with a basal bed of varying thickness containing a fauna of pre-Pleistocene aspect, amongst which the genera *Halotis* (absent from these coasts at the present day), *Pleurotomaria*, *Meiocardia*, etc., are noticeable.' This basal coral-rock was deposited on a submerged surface of faulted and denuded ridges of Scotland Beds alternating with areas and mounds of the Oceanic Series, and it filled up the hollows between these irregularities of the submerged platform. The main mass of coral rock commenced to form on this partly levelled surface. The coral rock¹⁴⁵ attains its maximum thickness of 240-250 ft. at some of the highest parts of the island (e.g. at Hackleston's Cliff, 997 ft.)¹⁰⁹, but the highest coral rock is not necessarily the oldest, for, according to Trechmann¹⁴⁵, the uplift has not been directly vertical but oblique and differential, the tilting having raised the east and north sides to a greater extent than the rest of the island.

Tectonics.—As regards the structure of the island, Beeby Thompson¹⁷⁰ considers that the tectonic features of the island result from an intense folding and in places overturning of the Scotland Beds, the axes of the folds running mainly north-east to south-west. After the elevation and denudation of these beds the Oceanic Series was deposited, and then followed a gentler folding with the axes of the folds more nearly east and west. Matley¹¹⁷ is of opinion that the island does not lie on the fold system of the Greater Antilles, but recent gravity investigations¹⁷² are regarded as proving that it does belong to the same arc; Rutten¹⁴⁹ also holds that it lies on a continuation of the Venezuelan Cordillera. Senn¹⁹⁰ has traced the development of the arc on which it lies from late Mesozoic through Tertiary times and figures the arc as completely embracing the Caribbean Sea.

Red clay and loam of recent origin are spread all over the higher parts of the coral area, being thickest on the highest plateau; they point to a long period of gradual distintegration and solution of the coral rock, for 1 cub. ft. of red clay is calculated to require 50-60 cub. ft. of coral rock for its production.

3. THE THIRD OR OUTERMOST ZONE OF THE ANTILLES

This zone, as above stated, only attains a considerable width or importance at its northern end, decreasing rapidly southwards, where it is only represented by a few small insignificant islands.

The **Bahamas**^{28 29 114 115 139 146 172} occur at the northern and wider end of the outermost zone, and consist of a group of about 3000 low coral islets, rocks, and banks, having a total area of 4500 sq. miles. The islands occur either on one of two large banks, known as the Little and Great Bahama Banks¹⁴⁶, or they rise as isolated eminences to the south-east of the latter bank. They are merely the sub-aerial protuberances of extensive slightly submerged plateaus, which on one or more sides rise precipitously from oceanic depths of 1000 to 3000 fathoms⁵⁹. Fault zones apparently bound the Bahama block. The islands are composed entirely of calcareous coral sand of æolian origin, varying from a fine-grained compact oolite to a coarse-grained rock composed of angular or rounded fragments. Some of the rocks are loose and sandy, others are hard and compact. They frequently show false-bedding and irregular stratification. Interformational conglomerates also are found. Fragments of corals, and mollusca and fine calcareous sand enter into the composition of the rock, and Nelson²⁹ records numerous species of corals and shells, including *Strombus gigas*, *Turbo pica*, *Venus (Lucina) pennsylvanica*, *Pupa chrysalis*, etc. The fossils belong almost entirely to living species. Some of the oolites are of marine origin and contain corals, gastropods, and lamellibranchs; the marls contain chiefly land or fresh-water forms, but on the west coast of Andros they are chiefly brackish-water or marine forms. In others there is a mixture, as would be expected in æolian formations in low-lying islands. Deep bores¹⁷² are said to have entered Miocene rocks.

The rocks must have been formed by wind action when the banks down to the 10-fathom line were an irregular mass of low land. According to Agassiz, a subsequent submergence to an extent of 300 ft., which was accompanied by marine erosion, resulted in the production of the numerous separate islands and submerged banks, amongst which is the Great Bahama Bank, having a length of about 400 miles, and a maximum width of 250 miles. The Bahama block appears to have been unstable and to have suffered several vertical movements of slight extent with some tilting. The weathering of these calcareous rocks has produced the red earth which forms the soil of the Bahamas, as in Barbados and elsewhere. It is of much interest that the Algal Sediments¹⁹⁵ of Andros Island contain structures which are much like the fossils called *Collenia* in the Belt Series of Canada and the Dolomite Series of South Africa.

The **Caicos Islands**³⁰, which lie at the south-eastern end of the Bahamas, consist of limestones of undescribed character, and are chiefly remarkable for their marine-erosion caves situated inland in a low range of limestone hills. These caves have their floor covered with a deposit of red earth containing over 30 per cent, of phosphate of lime, which is considered to be the result of the weathering of great masses of guano.

Anegada, lying on the north side of the Anegada Channel, consists of coral sand and hard compact limestone containing numerous shells belonging to species now living in the Caribbean Sea.

Barbuda.—It is believed that the small calcareous islands and banks, such as Barbuda, at the north end of the Windward Islands, rest on volcanic

basements. The low undulating plain which forms Barbuda consists, so far as is known, of the White Limestone of Antigua. But Earle¹¹⁹ considers the limestones to be of Pliocene or Pleistocene age, with some thin deposits of Recent origin. Davis⁷⁸ considered that Antigua and Barbuda, with the 30-mile bank stretching between them, represent a tilted and partly re-levelled atoll, and that they indicate the second cycle in the development of these islands, the first cycle being the growth of volcanoes with eruptive rocks on which coral limestones were formed.

Sombbrero^{3 31} consists of limestone containing mollusca belonging to the existing marine fauna, with the exception of one species of *Bulla*. Beds of guano (formed at three periods), phosphatised limestone, and fissures filled with phosphates make the island of some economic importance⁷⁸.

ISLANDS WITH SOUTH AMERICAN RELATIONS

(1) TRINIDAD^{47 58 91 97 98 101 147 149 193}

The island, which measures 48 miles in length by 35 in width, may be regarded as a quadrangular plain traversed by three more or less parallel lines of elevation running in a general east-and-west direction, the northern range following the north coast and consisting of the oldest rocks, while the two parallel ranges to the south, one of which follows the south coast and the other crosses the middle of the island, are of younger rocks. The ranges rise on an average to a height of 1500-2500 ft., but a few peaks are over 3000 ft. The general geological structure is in agreement with that of the adjoining Venezuelan coast^{45 101}; the northern mountains of Trinidad, however, are not a direct continuation of the Parian Range of the mainland^{91 101}, but are parallel or sub-parallel to it and overlap it in the typical *en echelon* manner. It is held by Rutten¹⁴⁹ that the Venezuelan Cordillera does not run out into Trinidad, but extends north-east to Barbados. On the other hand, Lamare¹⁷⁴, in his map of Venezuela, makes the Cordillera continue directly into the Northern Range, and the rocks which compose it show a remarkable similarity^{87 174}. Three principal periods of movement in the building of the island have been recognised, the first of which took place in pre-Cretaceous times and intensely folded and metamorphosed the old rocks of the northern range, the pressure acting in a N.N.W.-S.S.E. direction. The Cretaceous strata were subsequently folded along N.E.-S.W. axes. The Tertiary beds were subsequently laid down on an irregularly eroded series of ridges, of various heights, having approximately a N.E.-and-S.W. trend. While the Tertiary beds were being deposited the third crustal movement began, but in this case the flexuring took place along east-and-west axes, ultimately producing a series of well-defined more or less parallel anticlines and synclines obliquely directed to the former folds. Five at least of such anticlines have been recognised⁹⁷. One such crosses the island from Galeota Point to Galfa Point, a second from Mayaro Bay to

Point Fortin on the Gulf of Paria, a third from north of Mayaro Point to the Vance River, a fourth is seen at San Fernando, and a fifth more or less coincides with the central range. There is evidence that the flexuring movements have not yet ceased.

Stratigraphical Succession^{25 83 46 47 52 91}.—There are four more or less clearly defined regions in the island, each marked by a different development and character of the beds, and, owing to the employment of different names in these areas for the various types of deposit, there has been much confusion and difficulty in their correlation. The Northern Range, the Central Range, the intermediate lowlands to the south of it, and the Southern Range, together with the so ith-west of the island, constitute these four divisions, and must be treated to a great extent separately. Wall and Sawkins and many subsequent authors grouped the beds into the following three systems (in descending order), which correspond respectively with the Metamorphic, Cretaceous, and Tertiary groups above mentioned :—

3. Newer Parian (Tertiary).
2. Older Parian (Cretaceous).
1. Caribbean System (Metamorphic).

But the terms Newer and Older Parian are rarely used now, and Waring's⁹¹ classification and nomenclature are here adopted, as they seem to be the most, satisfactory, though Guppy^{16 20 26 35}, Dall¹³, Liddle¹⁰¹, Cunningham Craig⁴⁶⁻⁵²,

	Central Range	Intermediate	Lowland
<i>Pliocene</i> .	Matura Formation		
<i>Upper Miocene.</i>	Caroni Formation		Upper Moruga Formation.
<i>Upper Middle Miocene</i>	Manzanilla Formation	Poonah Sand	Lower Moruga Formation.
<i>Lower Middle Miocene</i>	Machapooria Forma tion	} Naparima Sries	Naparima Series.
	Tamana Limestone		
<i>Lower Miocene</i> .	Upper St. Croix Formation	Upper St. Croix Formation	Upper St. Croix Formation.
<i>Oliocene</i> .	Lower St. Croix Formation	Lower St. Croix Formation	Lower St. Croix Formation.
	(uneonformity)		
<i>Upper Eocene</i>	Mt. Moriah Forma- tion	Mt. Moriah Forma- tion	Mt. Moriah Forma tion.
	(unconformity)		
<i>Lower Eocene</i>		Tarouba Shale	Marac Formation.
		San Fernando Argiline	
	(unconformity)		
<i>Upper Cretaceous</i>	Point a Pierre Grits.		
<i>Lower Cretaceous</i>	La Carriere Shale .		
	Upper Caribbean Series (<i>Jurassic</i> in part) }		
	Lower Caribbean Series		
	Igneous (granophyre)		

The Caribbean System forms the northern chain in the island, and the strata of which it is composed have suffered complicated folding, being arranged in a fan-structure, but only the northern half of this structure is seen in Trinidad. The beds are intensely folded and frequently repeated, and shearing, contortion, and minute puckering have also taken place. The movement acted in a N.N.W.-and-S.S.E. direction, and produced in the rocks considerable metamorphism, which is less intense in the eastern part of the island. Amongst the rocks we find limestones, mica-schists⁹¹, talc-mica-schists, quartz-schists,

graphitic schists, etc.⁸⁷, and where the beds are less altered they are represented by quartzites, sandstones, grits, conglomerates, and carbonaceous shales or slates. The succession of the sediments remains to be determined, but a large number of fossils have been recorded which are supposed to be of Palaeozoic age, and some of them have been identified as belonging to the genus *Murchisonia*, while a few obscure corals have been determined as *Favosites* and *Petraia*. But these identifications are doubtful, and probably the so-called *Murchisonia* belongs to the genus *Nevinæd*, for Trechmann^{72 111} has recognised that genus from the *Laventille Limestone*⁹¹ which occurs in the upper part of the Caribbean System and suggests a Jurassic or Cretaceous age. Recently Spath¹⁵³ has recognised Tithonian (Upper Jurassic) ammonites from a locality in the Northern Range, so that it is probable that beds of more than one period enter into its complicated structure. A cephalopod supposed to be a goniatite and a fish referred to the genus *Acanthodes* from the neighbourhood of Port au Spain are also of uncertain generic identification. On the mainland the relations of the Cretaceous of Venezuela to those rocks which are regarded as corresponding to this Caribbean system of Trinidad are such that the latter must be at least early Mesozoic, though possibly Palæozoic⁴⁵. Cunningham Craig⁴⁷, however, is inclined to regard the Caribbean beds of the Northern Range to be not older than Jurassic, and possibly merely altered Cretaceous^{72 111}.

A mass of intrusive epidiorite⁴¹ or granophyre⁹¹ in the Sans Souci district seems to be a sill, and a similar rock occurs in the igneous complex of the island of Tobago.

The total thickness of the strata in this Metamorphic Series is estimated by Cunningham Craig at not more than 1000 to 2000 ft.

Lower Cretaceous.—This division^{91 127} is represented in the Central Range and near Point a Pierre at its western end by shales (*La Carriere*), some lenticular masses of limestone which have yielded rudistids¹⁰² and other mollusca⁸⁸, including cephalopods (*Crioceras*). The formation extends along the southern flank of the Central Range, and in the eastern part of the island the limestone-bearing part is exposed on both the south and north flanks of Mount Harris, where the best preserved fossils have been found.

The **Upper Cretaceous** is composed of sandstones, shales, and grits, the whole formation being known as the *Point a Pierre grits*, and it extends to near the eastern side of the island. Numerous foraminifera^{116 157} have been described from it. The most characteristic fossil is *Roudairia*¹⁰², and Rutsch¹³⁷ has recently described a species of *Hamulus* and one of *Sphenodiscus* from Point Bontour, where Harris¹⁰² obtained species of *Ostrea*, *Psilomya*, and *Roudairia* comparable with species from North Africa. Thomas¹⁴¹ has described species of sponges and corals from these beds, and Vaughan and Cole¹⁹¹ have dealt with the foraminifera.

Tertiary.—The true succession of the Tertiary rocks is rendered peculiarly difficult of interpretation because of the great lateral variation which takes place in their lithological characters, as above mentioned. Estuarine, shallow-water, and deep-water formations were being laid down at the same time in adjacent areas owing to the existence of contemporaneous conditions of different character within short distances. The problem is complicated by the fact that the beds overlap the Cretaceous unconformably, and that the local succession is not everywhere complete. In addition, progressive earth-movements took place during their accumulation, so that the older Tertiary beds were here and there denuded before the deposition of the younger members. On the north and south sides of the main Cretaceous anticlinal ridge

the development of the beds is different, and Wall and Sawkins consequently gave them distinctive names.

Not only is there a variation in the nature of the Tertiary beds in the southern, central, and northern districts, but traced from east and west the variation is likewise conspicuous. Thus, in the Cunapo coal-field the horizons of lignite seams can be traced in the course of a few miles eastward and westward through conglomerates and sandstones into fine marine clays and even foraminiferal limestones.

The precise correlation and classification of these various deposits, which bear many local names, have not yet been thoroughly carried out, for the observations in the field are somewhat disconnected and incomplete.

Eocene.—The lowest Tertiary bed, according to Waring⁹¹, is the so-called *Marac Formation*, typically exposed in the Southern Range. It consists of thin beds of silt and clay with highly-calcareous sandstones containing many fossils which indicate the Lower Eocene. It is well developed also on the Soldado Rock^{34 127 128 136 142 187 196} in the Gulf of Paria, where it has yielded a large fauna allied to that of the Lower Eocene of Alabama and Pernambuco. Some of the characteristic fossils from the Marac Quarry are *Hercoglossa* [*Aturia*] *ulrichi* var., *Venericardia planicosta*, *Calyptrophorus velatus* var., *Turritella neinea*, *Mesalia promila*, and *Linthia alabamensis*. But Douville⁵⁸, on the evidence of the foraminifera, regarded these beds as of Lower Oligocene age. There is a peculiar rock of a uniform texture and apparently a silicified clay or shale, known as the *San Fernando Argiline*^{91 95}, on the San Fernando or Naparima Hills in the Intermediate Lowland, containing fragments of radiolaria²⁶ and other small fossils. The bed is also exposed at several other places in the Intermediate Lowland and on the Southern Range. It is about 1600 ft. thick, and is of doubtful age—perhaps Cretaceous—but Waring⁹¹ puts it as Lower Eocene. Bituminous impregnations and calcite veins occur in it. Overlying this, on San Fernando Hill, is a softer more shaly variety of the bed, known as the *Tarouba Shale*, 300 ft. or more thick. A basal conglomerate (the *Plaisance Conglomerate*), and some superjacent sandstones, shales, and limestones, some of which contain fossils of Upper Eocene or Oligocene age, are known as the *Mount Moriah Formation*, and occur in the Central Range. Douville⁵⁸ has described *Orbitoides* from the limestone. This *Mount Moriah Formation* occurs also in the Intermediate Lowland and Southern Range, and here an orbitoidal limestone occurs at Bontour Point containing foraminifera—*Asteracites asteriscus*, *Isolepidina trinitatis*, *Helicolepidina spiralis*¹⁹¹, etc. Other fossils from Upper Eocene exposures at other places in the island comprise *Echinolampas ovum-serpentis*⁷⁷, *Rotularia clymenoides*, and species of *Lepidocyclus*.

The **Oligocene** is represented by thick deposits of foraminiferal silts and clays with some sands, passing up into the Miocene. It has been called the *Lower St. Croix Formation*, and it occurs in the Central Range, Intermediate Lowland, and Southern Range. It includes the deep oil-sands of Tabaguite and Lamont Estate. Only a few species of foraminifera and mollusca occur in these beds.

The **Miocene** begins with the **Upper St. Croix beds**, which are correlated with the *Lower Miocene* and comprise silty clays, frequently foraminiferal, with thin limestones, globigerina marls, pebbly clays, and some sandstones, including the *Herrera Sandstone*. The beds, which have a variable development, occur in the Central Range, and also in the Intermediate Lowland and Southern Range. A characteristic fossil is *Amusium pennyi*. Foraminifera are abundant, and so are corals, especially the genus *Orbicella*. The whole St. Croix Formation varies in thickness, and in places attains to about 3000 ft.

The **Lower Middle Miocene (Naparima Series)** is widely distributed in the Naparima district, and comprises fine-grained deposits, chiefly foraminiferal⁹⁶ and radiolarian clays and marls; it is divided into the **Lower** and **Upper Princes Town Marl**, which are again subdivided. The Upper division contains 90 per cent, of *Globigerina*, and consists of buff or white chalky deposits. This **Naparima Series**^{13 26} is developed in the Intermediate Lowland and Southern Range as well as in the south-western part of the island. Some geologists¹³ place it in the Oligocene. The *Naparima Marl*^{52 96} is developed on the south side of the San Fernando ridge, and is replaced on the north side by the *Green Clay*, according to Illing⁹⁵, having been deposited in separate basins. The marl is a shallow-water lenticular deposit. In the Central Range the *Tamana Limestone* may represent it. In the south-west of the island in the Palo Seco area¹⁹² the Forest Sands and Cruse Sands of the Naparima Series are correlated with the Lower Middle Miocene; they produce most of the oil, and correspond partly with the Green Clay of the Intermediate Lowland and with the Machapoorie Formation and Tamana Limestone of the Central Range. At Point a Pierre, Guppy²⁶ described a bed full of *Cadulus* ('*Ditrupa*'), with some pteropods, foraminifera, etc., as being the lowest bed in the Tertiary Series, but Ball¹³ considered it to belong to the Upper Oligocene. Waring⁹¹, however, considers it as equivalent to the lower part of the Tamana Limestone, and therefore of Lower Miocene age. The representative of the Green Clay on the northern flank of the Central Range in the island is the so-called *Machapoorie Formation*, a series of calcareous shales and limestones containing abundant fossils (*Turritella altilira*, *Cardita* sp., and *Cytherea*). Mansfield⁸² puts this fauna as Lower Miocene. Above the Green Clay is a red-weathering clay characterised by *Cyclamina cancellata*. Towards the south-west the formation becomes more sandy, and, together with the Green Clay equivalent, contains productive oil-sands.

The mud volcanoes of Cedros^{49 91 98}, Monkey Town, Guayaquayare, and those east of the Upper Ortoire occur in connection with the Naparima or St. Croix Beds, and together with the oil and asphalt lie along anticlinal folds, or along fault-zones⁹¹.

The upper part of the Middle Miocene comprises the **Manzanilla Formation** of marine deposits in the Central Range and includes the *Brasso Clay* and *Brasso Conglomerate*, together with sandstones and sandy shales. Fossils are abundant⁸². These beds occur on both sides of the range and reach a thickness of 4500 ft. on the west coast. The Brasso conglomerate is a prominent member of the series. At Mount Pleasant Quarry, lying above this conglomerate, the calcareous shell-bed, which Guppy termed the Springvale horizon, 20 ft. thick, contains an abundant fauna. Mansfield⁸² referred this bed to the Upper Miocene. Characteristic fossils of the Manzanilla formation are *Pecten demiurgus*, *Arca trinitaria*, and *Chione walli*. Along the south-east coast the upper part of the Middle Miocene is represented by the *Lower Moruga Formation*, which consists mainly of locally cross-bedded sandy deposits alternating with thin or lenticular calcareous sandstones and carbonaceous silts of estuarine character but with a few marine horizons. At Mayaro Point the Lower Moruga is nearly 3600 ft. thick. From their type exposure in Morne l'Enfer the Moruga beds are often termed the Morne l'Enfer beds. Along the northern portion of the Intermediate Lowland the Lower Moruga is believed to be represented by sandstones, sands and clays, known as the *Poonah Sands*, up to 500 ft. thick.

The **Upper Miocene** is represented in the south by the **Upper Moruga or Upper Morne l'Enfer Beds**, including probably the La Brea sands and clays in the south-west. The beds consist of silts, carbonaceous clays and sands

with vegetable matter. Some of the clays have been naturally burned to form the so-called 'porcellanite' of Wall and Sawkins. Plant-remains are common⁹⁰. The beds have a thickness in places of 1500-2000 ft. On the north side of the Central Range the **Upper Miocene** is represented by the **Caroni Beds** or **Carbonaceous Series**. A very varied succession of clays, conglomerates, shales, often carbonaceous, coals or lignites, and sands points to deposition in estuaries or lagoons with some shallow-water marine beds, in all reaching a thickness of over 2300 ft. on the east coast. These beds have yielded well-preserved plant-remains⁹⁰ of Upper Miocene age resembling those in similar beds in Venezuela. The Miocene faunas of Trinidad have been described in numerous papers by Guppy, Maury^{34 92}, Mansfield⁸², Vokes^{180 187}, and others (for further references see Waring⁹¹). Amongst **mammalian** remains¹⁸⁶ from the Tertiaries of Trinidad are the Miocene *Mastodon andium* and *Megatherium* sp. which are typical forms from the continent of South America.

The **Pliocene** occurs in Matura Bay on the east coast as an iron-cemented sand or conglomerate full of molluscan shells of which many species are still living.

The **Pleistocene** deposits are represented by Raised beaches⁴⁶ and sandy beds on the coast, by bedded gravels at the southern base of the Northern Range, and by river alluvium. From the Oropouche Formation, Berry¹⁸³ has described a small Pleistocene flora in the west of the southern part of the island.

Economic Geology

Petroleum¹⁷⁰ and **Asphalt** are widely distributed through the Tertiary rocks, and occasionally the Cretaceous beds are impregnated by oil derived from them. The oil occurs on several horizons. According to Waring⁹¹ the principal oil-bearing strata are the Miocene *Lower Moruga* sands and the *Forest Sands* of the Naparima Series in the south-western part of the island. The Naparima Series is the most important^{98 192}. On the south flank of the Central Range oil is also obtained from the *St. Croix Beds*. The oil is considered to have originated in the thick foraminiferal marls and clays of the Naparima and St. Croix formations, but some may have been formed in older beds⁹¹. In the Cedros peninsula the Miocene is estimated to reach a thickness of 7000 ft.⁹⁸, but the thickness and character of all the beds vary much laterally, which makes their correlation in different areas of the island a matter of great difficulty^{91 97 98}. The Lower Tertiary⁵² oil-sand occurs in the Galeota Group (Lower Moruga); the Rio Blanco petroliferous beds are in the Middle Tertiary, and the La Brea oil-sands in the Upper Tertiary of Cunningham Craig's classification. The oil bearing areas are situated on a series of anticlines running across the island from east to west, and their course is also marked frequently by escapes of gas, outflows of asphalt, and the presence of mud Volcanoes. The famous Pitch Lake of Trinidad, near Point La Brea^{25 33 39 40 52 91 97} is connected with the development of these beds, and is

situated on the denuded summit of a gentle anticline running roughly east and west, forming a shallow basin. The 'pitch' is derived from the La Brea oil-sand, having exuded from the truncated edges of the bed. The lake lies in a shallow depression on a small raised plateau and covers about 137 acres, and the thickness of the deposit is known to exceed 13 ft. The bitumen has flowed down over much of the surrounding country, and continuous exudation is still taking place.

The fissures in the Tertiary rocks filled with Manjak derived from crude petroleum are of importance in the San Fernando field^{51 91}, and go down to depths of 200 ft.

(2) TOBAGO

The island of Tobago, 26 miles long and 7½ miles wide, rises to a height of about 1900 ft. and rests on the north-easterly extension of the continental shelf which supports Trinidad; its mountains agree in structure and lithology with the northern mountains of Trinidad, being composed almost entirely of metamorphic rocks with intrusive basic igneous rocks, and they may be regarded as the last step in the echelon plan of the littoral Cordillera³². These metamorphic rocks also include schistose grits, talcose and talc-mica schists, closely resembling some of the rocks of the Caribbean Series of Trinidad. More than half the island is composed of this basic igneous rock which was apparently involved in the metamorphism, but there seems to be a variety of petrological types. Tertiary beds¹¹⁰ are thin and occur in patches to the east, west, and south-west of Scarborough town. The basal bed is a conglomerate. The brown clay and clay-ironstone contain *Area patricia* and other Upper Miocene fossils, especially *Balani*. *Area patricia* characterises the Upper Caroni beds of Upper Miocene age in Trinidad. The red or brown nodular clay or 'Tobago Crag' is seen in Rockly Bay, and is full of *Balanus*, *Pecten*, *Conus*, and *Fasciolaria* {*Xancus*} *semistriata* which is an Upper Miocene species. White marls¹¹⁰ cap a hill near Scarborough, and contain large and small oysters and *Balani* and nodules of *Lithothamnion*, with pebbles of epidiorite, and may be of Pliocene age. Coral-rock¹¹⁰ covers the southerly flatter part of the island, rising to a height of 120 ft. Gastropods and corals occur in it, and apparently all belong to living species. A Plio-Pleistocene age for the rock is probable.

- It is believed by many geologists that the materials for the oldest rocks in Trinidad, Tobago, and Barbados as well as Brazil, were derived from land extending to the east and north-east which existed during Cretaceous and early Tertiary times, but then was gradually submerged, finally disappearing beneath the sea in Middle Tertiary times. The Brazilian *massif* of ancient crystalline rocks which

extends into British Guiana is thought to represent the western end of this shattered and sunken continent which formed a true Atlantis.

GEOLOGICAL HISTORY OF THE WEST INDIES⁵⁹ 103 121 122 124 147

Owing to the great difference of opinion regarding the age of some of the Tertiary formations in the West Indian Islands and the consequent absence of any universally accepted correlation, it is difficult to give a satisfactory history of the movements of the area. The diverse interpretations and complicated theories^{85 89 103 121 124 147} 149 155 159 166 172 of the origin of the submarine configuration of the region have much increased this difficulty for, according as we regard the valleys and ridges, the channels and banks, as due either to sub-aerial denudation or to submarine erosion or to crustal dislocations, so do the estimated number and extent of the submergences and upheavals vary. The general geological history of the area has been summarised as far as possible by Vaughan⁵⁹ and Schuchert¹⁰³. The principal tectonic lines of the perimeters of the Gulf of Mexico and Caribbean Sea are believed to have been marked out at the close of the Palaeozoic ; the northern, western, and southern boundaries had by that time been defined, and the major transverse trends also formed. The positive and negative areas established at this early stage dominated the subsequent tectonic development of the area¹⁷². During early Mesozoic times we have no direct evidence of earth-movements, but in Upper Cretaceous times there was extensive submergence throughout the West Indies and Central America. In certain parts there is evidence of volcanic activity prior to this stage. No early Eocene sediments are known except in Trinidad, and the West Indies are supposed to have been raised above sea-level from the end of the Cretaceous till late Eocene or Oligocene times. According to Schuchert^{103 156}, in late Cretaceous and early Eocene times the chief orogenic movements took place ; the folding was very extensive, but followed much the same lines as those of the late Palaeozoic in the area^{103 121}. The dominant anticlinorium convex to the north extended from British Honduras across the Antillean Sea through the Caymans into south-eastern Cuba, and thence diagonally across Haiti-San Domingo into Porto Rico, probably terminating in the Virgin Isles. Another subsidiary anticlinorium stretched through southern Guatemala into northern Honduras and the Honduras banks and probably into Jamaica. Between these anticlinoria lay a valley which, during late Cainozoic time, subsided beneath the sea. The folding in the principal mountains of Jamaica, in the Sierra Maestra of **Cuba, and probably** in other islands occurred at this Cretaceous-Eocene stage. **In Upper** Eocene and Oligocene times there was a widespread submergence

and it was continued into the Miocene when Barbados may have sunk 5000 to 10,000 ft. The final diastrophic period began late in the Miocene, uplifting much of the Central American-Antillean region but also deepening the basins of depression. These movements were chiefly of an epeirogenic nature accompanied by block-faulting, and were specially intensive in Pliocene times, the 'Bartlett deep' 85 172 being then formed.

There have been many later¹²⁴ oscillations of the West Indian area, and some deformation has taken place. There has also probably been more than one temporary connection of several of the land-areas and of some of the islands, as seems demanded by biological evidence¹⁴⁷. The block-faulting broke up several of the old ridges and land-areas. Local submergences were a feature in Pliocene times, but the Pleistocene was marked by the emergence of large areas, and was accompanied by differential crustal movements. This Pleistocene emergency and the subsequent partial submergence in Recent times are by some geologists connected with the processes of glaciation and deglaciation which affected the level of the water in tropical regions.

Spencer^{45 175} has founded his theory of the origin of the present submarine features on the supposition that they are due entirely to sub-aerial denudation during several distinct periods of elevation. Most geologists now consider the same features as the results of crustal movements such as faulting, or folding of the rocks, or even as due to the removal of the calcareous materials by submarine solution. The profiles of some of the islands clearly suggest faulting along their margins^{57 85 89}. The hypothetical earth-movements, which are supposed to be expressed in the topography both terrestrial and submarine, Spencer holds to have been much larger during Pleistocene or Recent times than is generally admitted, for he estimates that they were to the extent of several thousand feet, and were repeated at various intervals, the maximum elevation occurring at the close of the Pliocene or in the early Pleistocene, and being as much as 7000 ft. At this stage, in his opinion, all the islands were united into a continental mass, but subsequently a submergence to below the present sea-level allowed of the accumulation of the gravels of the Columbia Series.

Gregory's²⁴ interpretation of the history of the Caribbean area in Tertiary times is entirely different, since he denies the existence of any continuous land-area or of any important emergence since early Miocene or possibly Oligocene times. Hill^{10 36} likewise rejects Spencer's extreme views, and considers that the irregularities of the submarine configuration of the West Indian region are partly orogenic and tectonic, and not due to submerged continental drainage-systems, while he holds³⁶ that the Windward

Islands are not due to crustal movements, but are simply islands of volcanic accumulation ('constructional volcanic piles') with here and there a veneer of marine calcareous deposits, and that there is no evidence that at any time the West Islands were connected with the North American continent, though the mammals suggest an early or Middle Tertiary connection with South America. Schuchert's¹⁰³ views on the history of the Caribbean region, being based on the most recent researches into the geology and correlation of the structure and formations on the various islands as well as the mainland, deserve especial attention in the face of previous conflicting theories. Bailey Willis¹²⁴ has propounded the theory that the Caribbean¹⁸¹ basin, by its subsidence, has exerted pressure against its margins causing their upthrust and folding, and that the process has been intermittent and has locally resulted in the elevation or depression of blocks. The present earthquake-lines¹⁵⁶ follow the main tectonic lines of the Caribbean area¹⁵⁵.

The resemblance of the marine faunas of the Mediterranean and West Indian seas in Oligocene and early Miocene times^{75 159 164 165}, to which attention has already been drawn, appears explicable on the supposition of a former shallow-water connection across the central Atlantic (as Haug suggested in his palæogeographical maps), which was broken across by the formation of the modern Atlantic trough. Suess held that the West Indian Tertiary sea was at the west end of his Mediterranean Tethys. Duncan¹⁹ recognised many years ago that several Tertiary species of corals from the Castel Gomberto Beds in Italy occurred in the Oligocene of the West Indies, and the affinities of the Maltese echinoids and foraminifera with those of the Caribbean area have been demonstrated by much recent work. The theory of a land-bridge^{169 188} stretching across the mid-Atlantic in Tertiary times has been supported by some zoologists¹⁸⁸, but rejected by others. But the remarkable relations of the marine faunas^{162 164 165} at that period indicate that they must have belonged to the same zoogeographical province. Rutsch^{159 168} believes that these affinities can be better explained by the theory of continental drift.

THE BERMUDAS¹⁷⁷

The group of more than 100 islands and islets, known as the Bermudas and with an area of 250 sq. miles, lies on a solitary elliptical submarine platform, of which the longer axis runs N.E. to S.W. It rises from the depths of the North Atlantic about 680 miles from New York, and the surrounding ocean is 2500 fathoms deep. The main islands form a hook-shaped line along the south-eastern edge of the platform. The interior of the larger islands is hilly and irregular, the ground rising in parts to a height of over 260 ft.

The peculiar form of the Bermudas and the greater height of the land on the south side seem to be due to the prevailing winds blowing from the south-west, and the hills are all sand-dunes more or less consolidated.

The present dry land is the mere remnant of a much larger limestone island, the former extent of which is indicated by the outermost of the surrounding reefs. An elevation of a little over 10-12 fathoms would convert the land-area from $19\frac{1}{4}$ sq. miles to 230 sq. miles in extent.

Geology^{41-43 53 54 66 108 134 135}.—All the rocks which can now be examined are of æolian origin, except in one case, but by boring it has been proved that there is a substratum of volcanic rocks⁵⁴, and it is maintained that the platform represents the degraded summit of a volcano which Verrill⁴² thinks was of Triassic age like the latest great volcanic eruptions on the nearest parts of the American continent.

This volcanic platform⁵⁴, which has been struck at a depth of 695 ft. from the surface (560 ft. below sea-level), consists of melilite basalts and other types of rocks related to monchiquite, together with some trachyte; it seems to represent the truncated top of a low cone mainly composed of basaltic lava like Hawaii. The petrological characters of the volcanic rocks are said to be like those of the Azores and Cape Verde Islands.

Resting on these lavas (which have been pierced to a depth of over 1400 ft.) come sands and gravel of water-worn volcanic debris about 100 ft. thick and mostly unoxidised, and these are succeeded by altered volcanic fragmental material which has been oxidised and is of the nature of land-waste derived from the volcanic area when exposed to sub-aerial weathering. Foraminiferal limestones follow, indicating a movement of depression beneath the sea, and covering a period ranging from the Eocene or Lower Oligocene to the Miocene. Then elevation again took place, and the marine calcareous rocks were exposed to sub-aerial action, and a series of æolian limestones were formed, ranging in age from Pliocene to Recent, with peat deposits¹³⁵. It is in these limestones that the numerous caves exist¹³⁴.

Details of the Formations

The four principal geological formations of which the islands are composed are of an entirely different character from that of the older marine calcareous deposits, and have been named as follows in descending order⁴⁸. Sayles¹⁰³ has given the fullest description of them :—

4. Recent.
3. Paget Formation.
2. Devonshire Formation.
1. Walsingham Formation.

The **Walsingham Formation** is the oldest, and is referred to the Pliocene. It consists of an æolian limestone, mostly hard, homogeneous, compact, and crystalline, with the bedding planes and structure obliterated by the infiltration of carbonated water. It contains extinct species of land-shells (*Pæcilonites nelsoni*, *P. bermudensis*, etc.)^{177-177a 178 179}. Layers of red earth, 2-10 in. thick, lie between the beds of limestone, and at the top are 8 in. of red clay or soil. It is calculated that 1 ft. of this residual clay would result from the solution of 150 ft. of limestone, so that long periods of exposure and much denudation must have prevailed. Probably the emergence took place at the end of the Miocene, up to which time foraminiferal limestones had accumulated on the submarine volcanic platform.

The **Devonshire Formation** is a marine beach-rock of fine materials formed during a period of depression. Some of it lies now 12-16 ft. above sea-level, and it rests against the flanks of older ridges of the Walsingham beds. It contains marine shells and corals, many of which are not now living in the Bermudan waters. It is believed to point to a post-glacial subsidence which took place during the Champlain period¹⁰⁸. (See Section on *Canada*.)

The **Paget Formation** overlies the Devonshire, and consists of consolidated soft shell-sandstone of æolian origin, about 150 ft. thick. It contains shells and the remains of birds and turtles, and points to re-elevation of the islands.

The recent æolian deposits are sand-dunes composed of broken shells of marine mollusca, serpulæ, nullipores, etc., all in a fragmentary condition. As a rule there are no corals. The materials have been washed in from comparatively shallow depths, and the reef corals have not contributed to its formation. The deposit forms cliffs 30-50 ft. high on the southern shore.

Sayles¹⁰⁸ has drawn attention to the fossil soils interbedded between the æolian limestones and sandstones, and the epochs in which the 'æolianites' and soils were formed alternated. He would associate this series of alternating conditions with the glacial and interglacial stages of the Pleistocene, and with the concurrent changes in the sea-level due to the advance and retreat of the ice according to Daly's theory. The 'æolianites' would represent glacial stages and the fossil soils, of which he records six, the interglacial periods. Under this theory it was the fall in the sea-level at repeated intervals which led to the exposure of the submarine platform and its temporary existence as a land area when wind action and the formation of soil took place. Changes in the climate are postulated by Brady¹⁶⁷.

Recent.—Over much of the islands there is a red soil left by the solution of the limestones, and representing a long period of exposure to sub-aerial agencies.

The curious weathering of the limestone in places has led to the production of circular 'pot-holes,' and to the development of the so-called 'palmetto stumps,' the origin of which has been explained by the fact that the cavities are lined with a harder coating than the surrounding rock; this has led to the latter being worn away more rapidly, so that the circular pot-holes with their more resistant inner coating are left standing up above the surface as hollow stumps, resembling the trunks of the palmetto palms. Peat deposits¹⁸⁵ are also widespread. The coastal erosion which the Bermudas are still undergoing has been described by H. Prat¹⁵⁴.

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SECTION II.—BRITISH GUIANA

British Guiana^{1 2}, which has an area of over 100,000 sq. miles, structurally belongs to the great Brazilian *massif*⁶ of ancient crystalline rocks ; its geology is fairly simple and agrees with that of the adjoining Dutch colony^{11 17}. The coastal belt of country, 5-35 miles wide, consists of post-Tertiary accumulations, but the western and central portions of the colony are occupied by a great sandstone formation rising in the Pacaraima Mountains to a height of 9000 ft., with perpendicular cliffs of 2000 ft. and flat-topped summits and plateaus. The rest of the country is composed of the ancient crystalline rocks, and it is by the products of their decomposition and denudation that the plains and fluvial and coastal regions have been formed. These low-lying areas consist of alluvial sands, clays, and gravels of Pleistocene or Recent origin.

DETAILS OF THE STRATIGRAPHY

(A) Archaean^{3 4 12}.—The basal crystalline complex consists of two main groups. (1) Gneissose rocks, partly acidic, partly basic, sometimes massive and sometimes foliated. These are mostly grey or pinkish grey in colour, and have masses of diabase and gabbro associated with them. (2) Quartz-porphyrries, porphyrites, felsites, and hornblende-schists ; mica- and quartz-schists are also common. These all seem to be younger than the gneisses, and owe their foliation to dynamic metamorphism. Granites and granitites, with veins and tongues of aplite, are intrusive into them. The granites seem to have suffered less from metamorphism than the other crystallines, and it is possible that some are even younger than the overlying sandstone formation. There are also varieties of hornblende-granite and quartz-diorite amongst the intrusives. In the Upper Waini River area, North-West district^{12 19}, there is a great development of mica-schist and muscovite-granite in the north-eastern portion, intruded by a large sill and dykes of dolerite. An ' Acid-Intermediate Volcanic Series '^{12 13}, consisting of greenish-grey tuffs and tuffaceous phyllites, occurs in the south-western area, and along the eastern edge of the huge Aranka-Kokerit Mænaab granite-batholith, on the eastern margin of the district, there are hornblende-schists and amphibolites representing basic igneous rocks. Red phyllites extend over large areas, and there are hornblende-granites intrusive into the ' Acid-Intermediate Volcanic Series ' and into the metamorphic basic igneous rocks. The basic and acid metamorphic rocks are the oldest, and the dolerite dykes and sills are intrusive into them, but the granites are the youngest igneous rocks in these regions.

Rocks of the same Archaean Series extend into Dutch and French Guiana, Brazil, and Venezuela^{8 9 11}, and a detailed description of them has been given for the adjoining colony of Surinam (Dutch Guiana)¹⁷.

(B) The Sandstone Formation (Roraima Series).—This series of sedimentary beds consists of coarse conglomerates, red and white sandstones and red shales, and covers an area of about 10,000 sq. miles in the central part of the western region, extending into Venezuela and Dutch Guiana¹⁷. Its thickness is estimated at about 7000 ft., and it forms the highest land in the colony, including

the remarkable table-mountain Roraima^{2 5 16}. The famous Kaieteur Waterfall on the Potaro River is formed by the river falling over the edge of the sandstone escarpment. The Marina and Amaila Falls in the same district are formed in the same manner. The Roraima beds rest unconformably on the Archaean and lie nearly horizontal, dipping only slightly northwards, and the whole series is remarkably free from faults and dislocations. No fossils have been found in it, but some authors have provisionally assigned it to the Cretaceous, as beds of this age with similar characters and relations are found in Brazil and Venezuela; Dalton⁸ refers it to the Pre-Cambrian.

Intrusive dykes, veins, sills, and laccolites of diabase^{3a} are very common in the sandstone; they may be of Tertiary age, like those in the West Indies, if the sandstone is Cretaceous. Dalton, however, considers the intrusives to be of Mesozoic age in Venezuela. The diabase occurs in belts which usually stretch from north-west to south-east and may be of great size, sometimes even forming mountain ranges 2000 ft. high (e.g. the Eagle Mountains).

(C) **Post-Tertiary Deposits**²⁰.—The alluvial sands and clays, over 200 ft. thick, which contain much decomposing vegetable matter, rest on an older series of arenaceous clays of various colours, ironstone, gravels, loams, sands, ferruginous conglomerate and laterites, which Harrison⁷ calls the *residuary deposits.* These cover large areas, and form the characteristic soils and sub-soils. They are derived from the decomposition of the granites, gneisses, schists and other crystalline and igneous rocks, and differ in composition according to the nature of the original rocks. The White Sand Series is a detrital deposit, derived largely from the Roraima Sandstones; it includes the clays, silts, marls, and sands with leaf impressions spread throughout the lower parts of the colony. The placer-deposits of quartz-gravels, containing concretionary ironstone and occasional pebbles of altered basic rocks (epidiorites and hornblende-schists) are widespread.

ECONOMIC GEOLOGY

Diamonds are found in the alluvial deposits and gravels^{14 18}, but their source is unknown. They occur in the 'White Sand Series'¹⁹ north of the Kaieteur escarpment.

Gold^{10 13 18 19} occurs in the epidiorites and hornblende-schists in veins of quartz or diffused throughout the rock, especially where traversed by later intrusions of aplite or diabase. On the Barama River¹⁸ gold-reefs occur in sheared tuffs and manganiferous phyllites. The 'Acid Intermediate Volcanic Series' has been stated¹³ to carry all the gold in the Waini River area¹⁹, but it probably originated in the granite. It is also found at the contact of the intrusive diabase with the gneiss and in the diabase itself in the Potaro gold-field, and in the auriferous laterite and ironstone on the hills. The granite and gneiss are sometimes mineralised. Quartz-veins carrying gold also occur in the laterite. But the auriferous deposits of most economic importance are the placers or alluvial gravels which are widespread^{13 14}.

Bauxite^{7 15 31} has been discovered to form extensive deposits of great purity at Christianburg and Akyma, on the Demerara and Essequibo Rivers, and also on the Amakura River at Yarakita,

occurring as a residuary formation derived from the decomposition *in situ* of igneous rocks.

Manganese.—This mineral occurs in irregular masses in connection with volcanic rocks adjacent to quartz-hornfels¹⁸ along the Barama River.

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SECTION III.—BRITISH HONDURAS

British Honduras⁵⁻⁷ lies on the eastern side of the peninsula of Yucatan, and is bounded on the south and partly on the west by Guatemala. It has an area of over 7500 sq. miles, of which the northern and coastal portions are low-lying, but the surface rises gradually towards the interior, and in the south the country is altogether more elevated, reaching a height of 4000 ft. in the Cockscomb Mountains. The whole of the mountain area is really a peneplain at an elevation of 2500 to 3000 ft⁶. A fringe of coral reefs and islets lies at a distance of about 10 miles off the shore.

Geological Structure.—Structurally the northern part belongs to the peninsula of Yucatan¹, but the southern portion partakes of the complicated structure of Guatemala, for it is traversed by an extension of the Guatemalan folds which meet the sea in the Gulf of Honduras. The tectonic lines running through British Honduras belong to the north-east to south-west set which cross Central America and show virgation in doing so¹¹.

The oldest rocks are found in the Cockscomb Mountains, forming a horst bounded by faults. These mountains were originally part of a folded range and consist of granite, quartz-porphyry, serpentine, clay-slates, quartzites, quartz-conglomerates, and some limestones, but it is now considered that the granites and porphyries are intrusive into the limestones and associated sedimentary rocks which belong to the Upper Palaeozoic, and that their intrusion dates from the time of the earth-movements at the close of the Carboniferous. The limestones are crinoidal and have yielded species of *Fusulina*, and a coral referred to the genus *Lonsdaleia* has been found in the clay-slates. The beds are therefore referred to the Upper Carboniferous, which is more fossiliferous and better developed in the neighbouring countries. The strike of the beds is east and west or south-west and north-east, and agrees with that of the Guatemalan Range to the south, where *Fusulina* limestones, sometimes converted into marble, are found. The quartzites of the Cockscomb Mountains are said to be vertical, but the clay-slates have generally only a moderate dip. It is probable that older rocks than Carboniferous are included in the complex, and it is supposed that the whole Yucatan protuberance was outlined in Palaeozoic times.

The next beds in point of age consist of Cretaceous limestones and bituminous dolomites; these occur south of the Cockscomb Mountains, spreading out over wide areas to the west in Guatemala and Chiapas. Ower⁷ denies that there are any Cretaceous beds in

British Honduras, and states that the whole of the Mesozoic is absent. But Dickerson¹² records *Sphcerulites* and *Barrettia* from Cretaceous limestones, as in Guatemala.

A series of Tertiary limestones, involved in the Miocene folding, is present in the interior of the colony and on the coast north of Belize, and extends inland in a westerly or north-westerly direction across Guatemala and Chiapas, forming a band of variable width. Near St. Antonio Viego, in British Honduras, the foraminifer *Amphistegina* has been found in these beds, and the limestone contains other fragmentary fossils sufficient to prove it to be of Oligocene age. Powers⁴ has called it the Rio Dulce Limestone. These limestones, which are locally 1000 ft. or more in thickness, occupy the greater part of the Colony and extend westwards into Peten. They rest directly on the upturned edges of the Carboniferous slates.

In the south of the mountain area there occurs a younger series of Tertiary limestones, etc., which were deposited after the formation of the great mountain chains of Central America. These contain many flint concretions, and are probably identical with the rocks of Miocene or Pliocene age of similar character in Yucatan and Peten. In British Honduras and in northern Peten they are somewhat strongly folded. Ower^{6 7} terms these beds, comprising shales, mudstones, limestones, and calcareous sandstones yielding Miocene fossils, the *Toledo Series*; they are faulted down against the Oligocene limestones of the Sierra de Santa Cruz. Locally they are much disturbed and crushed, but in Yucatan they are scarcely disturbed. A bed of diatomite occurs in one place. Pleistocene fossiliferous limestones occur at Orange Walk and Richmond Hill in the extreme north, and extensive deposits of white clay, lignite marls, and sandstones are found along the coast (*e.g.* around Livingstone).

Tectonic Relations.—The whole structure of British Honduras is closely connected with that of the neighbouring parts of central America⁸ and the West Indies^{9 10}. The Caribbean Cordillera, which consists of the ranges in Guatemala and Honduras, trends mainly east-and-west, with a general concavity towards the north, and meets the coast-line at a considerable angle near the head of the j Gulf of Honduras. These axes were developed during the folding which took place at the close of the Palaeozoic period, but late Miocene movements of less intensity subsequently developed parallel folds. The Sierra de las Minas, which forms part of the Palaeozoic arc in Guatemala, has a zone of folded Upper Carboniferous, Cretaceous and partly Tertiary beds lying to the north of it, but the range appears to be let down by longitudinal faults against the foreland, and step-faults also traverse it. The Cockscomb Mountains

lie between two such faults, and it is probable that the serpentine intrusions which occur in them are of the same age as those farther south, *i.e.* younger than the Upper Carboniferous and older than the Middle Cretaceous. Ower^{6,7} considers that 'the mountainous portion of British Honduras appears to have risen as a block and shows no sign of folding since the intrusion of the granite,' and that it has remained a land-mass and suffered prolonged denudation until the Oligocene subsidence when the foraminiferal deep-sea limestones were deposited. In Miocene times an uplift occurred accompanied by faulting when the long north-and-south fault defining the coast-line was formed after the above-mentioned Toledo beds, which lie between the mountains of British Honduras and those of Guatemala, were deposited. The sea then washed the foot of the mountains, and the coastal plain, composed of later marine and alluvial deposits, was afterwards formed in Plio-Pleistocene and Recent times by another smaller uplift. All the igneous rocks appear to have come from the same granodiorite magma; some are interbedded, but the majority were intruded into the Upper Carboniferous sedimentary beds. The intrusions comprise granites, aplites, pegmatites, and quartz-porphyry, forming dykes, sills, flows, and probably ash beds⁷.

ECONOMIC GEOLOGY

Gold in small amounts has been obtained from the older rocks of the Cockscomb Mountains and from river gravels, and rubies⁵ (? garnets⁷) have been found in a blue fluviatile clay in the same region. Alluvial tin also is found in and near the granite outcrops.

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CHAPTER IX

CANADA AND NEWFOUNDLAND

General Characters²²⁹.—The Dominion of Canada covers an area of over 3f million square miles, and Newfoundland, which is 42,000 square miles in extent, is geologically a part of it. The whole geological history of British North America, which is naturally connected integrally with that of the rest of the North American Continent¹¹⁶, possesses certain features which are peculiar to it. There are six great natural divisions based on physical and geological features and structures into which the whole Canadian area falls¹⁹⁵, but they are of very unequal size : (1) The *Canadian Shield* or *pro taxis*³¹³, which is the largest and occupies nearly half the whole Dominion ; (2) the *St. Lawrence*, or *Laurentian region*⁴⁶⁰, which is the smallest division and consists of the plains bordering the lower part of the St. Lawrence River and extending westward to Lake Huron ; (3) the *Acadian* or *Appalachian region*¹⁶⁴ which forms nearly all the eastern sea-board of Canada ; (4) the *Arctic Archipelago* lying to the north of the Canadian Shield ; (5) the *Interior Plains*⁵⁸⁸ bordering the western side of the Canadian Shield and part of its southern side ; and (6) the *Cordilleran region*^{134 204} occupying a broad belt of mountainous country all down the western coast.

Of these features the first and most remarkable is the existence of an enormous outcrop of ancient crystalline rocks surrounding Hudson Bay in a U-shaped manner, and frequently termed the '*Canadian protaxis*' or '*Shield*'^{2 229 313 495 611}. The eastern limb spreads out as a region of relatively high ground occupying most of the Labrador peninsula, but the outcrop narrows considerably where it encircles the south end of Hudson Bay, being there bounded on the south by the River St. Lawrence and the Great Lakes ; from this district the western limb stretches north-westwards to the Arctic Ocean with increasing width, having the Winnipeg system of lakes, and Lake Athabasca, Great Slave Lake, and Great Bear Lake extended along its western margin. The only mountains on the whole of the Canadian Shield are those in the northern parts of Labrador, and they are due to a late Tertiary uplift.

The Archaean and Pre-Cambrian rocks, of which the great *Canadian Shield*²²⁹ 313 387 495 497 611 is composed, are surrounded by a ring of Palaeozoic rocks horizontally bedded (except on the south-east) and

resting with a great uniformity on the folded and eroded edges of the older rocks. Subsequent denudation and marginal faulting have determined the outlines of the Archæan mass, and much of its covering of later rocks has been stripped off ; but there is no clear evidence that this ' Laurentian plateau ' has ever been wholly submerged since Cambrian times, or that any large part of it has become an area of marine deposition since at any rate Upper Devonian time^{13 125 182 509}, when the Timiskaming region, and that south and perhaps west of Hudson and James Bays, and to the south-east and east of Hudson Bay, were covered by the sea. The lowlands⁴⁶⁰ at the south end of Hudson Bay are composed of scarcely disturbed Ordovician, Silurian, and Devonian beds forming part of the girdle of Palæozoic formations resting on the more ancient and denuded edges of the Canadian Shield. From the relations of the Palæozoic deposits to the older rocks, it is believed that the greater part of the denudation of the Archæan mass and the formation of the Laurentian peneplain were accomplished in pre-Palæozoic times^{125 126 509}, but that deformation and warping later took place²⁵⁹.

The south-eastern borders of the shield which constitute the *Acadian region* have a complicated structure which is in close connection with that of the whole of the eastern part of the United States, being traversed by the same series of Appalachian folds produced by tangential movements which were directed from the existing Atlantic, and affected the Palæozoic and older rocks which chiefly compose it. From Alabama to Georgia these folds strike north-east more or less parallel to the coast, thus forming the Alleghany Mountains, and are finally continued into the Catskill Mountains north-north-west of New York, where they are joined by a system of folds running from north to south, and having their western border extending along Lake Champlain. This meridional system reaches the St. Lawrence near Quebec, and then, with the trend curving to the north-east, follows the right shore of that river. There is overthrusting towards the north-west, and a great fault zone, consisting of a series of parallel or *en-dcheleon* faults, runs approximately parallel to the St. Lawrence River^{280 594}, and to the edge of the old Pre-Cambrian land for many miles¹¹, constituting part of the great Champlain-St. Lawrence fault (as described by Logan), which is one of the most important structural features in eastern Canada^{252 280}. But while the origin of the Gulf of the St. Lawrence^{378 594} is due to faulting²⁵², the shaping of it has been mainly caused by glacial erosion^{280 378 495}, and Shepard^{594 606} regards the Bay of Fundy to be a glacial trough. The St. Lawrence, in fact, marks an extremely important boundary line in the structure of the country, all the Palæozoic and older rocks on its right bank being folded along the north-easterly axes of the Appalachian

System, which are prolonged across the intervening sea into Newfoundland. The separation of Newfoundland⁹⁷ 252 253 378 from the mainland is due to submergence and transverse faulting of the margin of the continental platform. For Newfoundland^{249 263 286} 289 378 is only a detached portion of the Acadian region. The trend of the lines of folding, and the position of the anticlinal axes have determined the outlines of the coast of Nova Scotia, New Brunswick, and Cape Breton. The jagged coast of Newfoundland^{97 255} 263 289 is likewise directly the result of these folds which strike across the island in a south-west to north-east direction, the saddles forming peninsulas, and the bays for the most part corresponding to synclinals. These coasts are therefore of the true Rias type²⁸⁹. The main period of folding is older than the Carboniferous, as is shown by the he of the Coal Measures in New Brunswick, but folding movements did not go on after Permian times, for the Permian sandstones are in a horizontal position in Prince Edward's Island and in the Bay of Fundy. The chief periods of disturbance and folding in post-Pre-Cambrian times were the Taconic in late Ordovician, the Acadian in Devonian, and the Appalachian in post-Carboniferous times.

There is no similar boundary to the Canadian shield on the south and west, but on the south-east the Palaeozoic girdle constitutes part of the Lowlands of the St. Lawrence region, which is underlain by nearly horizontal strata ranging from the late Cambrian to late Devonian and is continuous with the widely-spread and little disturbed Palaeozoic rocks of the adjoining parts of the United States, while to the west it is covered by the transgressive Cretaceous beds of the central and western plains.

There is a noticeable and evident connection between the position of the Great Lakes and the course of the boundary line of the great ' shield ' in the south and west, though warping of the surface^{259 561} and glacial erosion²¹⁵ have likewise played an important part in determining their distribution³⁰⁴. The boundary line runs from the north-east end of Lake Ontario to the east end of Georgian Bay, and thence towards the west end of Lake Superior, the northern shores of which consist mainly of Archaean or pre-Palaeozoic rocks, the south side being composed of various members of the Palaeozoic systems. Farther to the north-west we similarly find the eastern shore of Lake Winnipeg composed of Archaean rocks, while the islands and the west shore belong to the horizontally bedded Palaeozoic girdle on which also lie Lakes Winnipegosis, Manitoba, and other smaller sheets of water. Lake Athabasca has flat-lying Palaeozoic sediments along its southern shore, but its northern margin and west end are of gneiss. Farther north the boundary line almost coincides with the Slave River, and to the east of the

mouth of this river Great Slave Lake^{198 365 376} is underlain by Archaean rocks, while west of it the floor is of Palaeozoic beds. A series of small lakes marks the boundary northwards to Lake La Martre, and the line then changes its direction and reaches the south-east part of Great Bear Lake^{355 364}, and follows the lower course of the Coppermine River to the sea, so that the eastern point of Coronation Gulf is of Archaean rocks; Cape Krusenstein on the west, however, is of Palaeozoic rocks. The Palaeozoic girdle to the west of it expands considerably so as to reach beyond the mouth of the Mackenzie River.

The *Arctic Archipelago*^{2 144 172 256 368 371 612 616}, which is composed of the shattered marginal portion of the North American Continent, due to the foundering of the Arctic Ocean and the accompanying formation of radial and transverse fractures, producing a typical fiord coast, shows fragments of the northern part of the Palaeozoic girdle^{144 163}, the beds becoming successively of more recent geological age as we proceed towards the Pole, but they cease to be flat-lying sediments and form a fragment of a folded mountain chain, comprising Carboniferous²³⁸, Triassic, and Jurassic marine beds beneath which the 'shield' plunges out of sight. This folded range was considered by Suess to present the characters of the Asiatic arcs and the Laurentian Shield to be related to it as a foreland. Baffin Land^{371 535}, eastern Ellesmereland^{158 612 616}, and eastern North Devon consist of Archaean rocks, and the axis of the Boothia Peninsula, which is prolonged northwards through the islands to Barrow Strait, is also formed of the same rocks. The south-western islands consist chiefly of Silurian and Devonian beds, which are continued northwards into Grinnell Land. Carboniferous rocks form the north-western members of the archipelago. The sounds and channels which are independent of the trend of the rocks have been determined mainly by faults³⁷¹. The Labrador coast is also marked by a series of fiords and channels which owe their origin to tectonic causes and follow the trend of fault-lines⁴⁷¹.

The next great geological feature of Canada consists of the *Interior Plains* lying between the western edge of the 'shield' and the Rocky Mountain Fold-System, the border of which meets the Palaeozoic girdle at an acute angle somewhere near Port Simpson, lat. 62°, long. 122° 306 588. This Interior Plain is almost entirely composed of mostly horizontal undisturbed Cretaceous beds, accompanied in places by some Lower Tertiary, but it is heavily covered with superficial deposits and the outcrops of rock are for the most part only seen in deep river valleys. The eastern boundary is the original rocky rim of the basin in which the strata were deposited, but the western margin was determined by the subsequent elevation of the Rockies. The Interior Plains may be divided

into the *Manitoba lowland*³⁰⁶, which forms the eastern part of the region, while its western boundary is marked by an escarpment forming the edge of the second division, the *Alberta upland*²⁶², which extends west to the Rocky Mountains and north-west to the latitude of Great Slave Lake, where it fronts the *Mackenzie lowland* which stretches north to the Arctic Ocean¹⁹⁵. The surface of the Alberta upland is nearly flat or gently rolling, but it rises to the west. Palaeozoic beds ranging from the Ordovician to the Devonian underlie the northern part of the Alberta upland, and also the Manitoba lowland and most of the Mackenzie lowland. Along the western edge of the plains region the beds are involved in the folding and faulting movements of the foot-hills. It is in the foot-hills that Devonian, Carboniferous, Triassic, and Jurassic beds crop out²⁵⁴, but Cretaceous beds also occur to a considerable extent in them, though the main area for Cretaceous beds is the plains over the greater part of which they spread, successively older beds of that system outcropping to the east. Tertiary beds also occupy large areas in the plains, and Pleistocene and Recent deposits are widely distributed over much of the surface. The Pleistocene glacial and post-glacial beds cover much of the old rocks of the Canadian Shield. The plain ascends gradually or in three distinct steps to the foot-hills at the base of the Rockies, where, at a distance of 12 to 20 miles, parallel longitudinal disturbances begin to appear as faults and gentle or even inverted folds which become overthrusts in the foot-hills.

Finally, between the western edge of the plains and the Pacific Ocean comes the important physical and geological feature, which has been described as the *Canadian Cordillera*; this includes the Rocky Mountain System^{148 191 204 439} and other ranges, for it is composed of a series of mountain chains with different geological histories and different periods of formation. The geological history of the Cordilleran region is the most varied and complex of all, and the different parts of it have very distinct developments^{191 199 200 202 204 241 264 294 314 315 318}. The Rocky Mountain System^{191 204 264 314 318 439} forms the eastern flank³¹⁵ of the great Cordillera²⁰⁴ which stretches from Bering Sea in the north to central New Mexico in the south, more or less continuously, but varying much locally in its history and structure.

In Canada the *Rocky Mountain System* may be regarded as bounded on the west by the great 'trench' termed the '*Rocky Mountain Trench*'^{200 202 315 511}, which runs in a general north-west to south-east direction east of the Selkirk and Purcell Ranges. It is not a '*graben*,' according to Shepard⁵¹¹, as its floor is occupied by beds older than those on its flanks; it extends from lat. 49° northwards to the Yukon for over 800 miles. It has had a complicated history,

being partly formed by tectonic causes and partly by erosion ; the southern part is due to orogenic movements at the close of the Jurassic and to faulting in Eocene times, while its northern portion was formed by normal erosion of intensely folded and thrust-faulted beds. It is now occupied by portions of several rivers, for the drainage system has been changed from time to time by earth-movements and river development leading to the capture, diversion, or beheading of certain of the rivers. In the south it is occupied by part of the Kootenay River and, farther north, by parts of the Columbia River, the Canoe River, the Fraser River, the Parsnip River, and the Finlay River⁶²⁰, all of which, except the last two, discharge into the Pacific ; the Parsnip and Finlay meet at lat. 56° to form the Peace River which bends sharply to the east and cuts across the Rocky Mountains to fall into the Mackenzie River System which flows north into the Arctic⁶²⁰. The Peace River is the only one, except the Liard, which cuts through the range, forming the Peace Pass. Farther north the Trench is occupied by the Fox River and beyond by a tributary of the Liard. The shorter " *Pur cell Trench* " ²⁰² is parallel to it, but wholly due to erosion, according to Schofield¹⁹⁹, and has not been formed by faulting. It has been cut in the upland plateau or peneplain formed after the Laramide (post-Cretaceous) orogenic event. Similar longitudinal valleys are the Selkirk Valley holding the Columbia River, the Okanagan Lake Valley, and the Fraser River valley, though the canyon of the latter has an individual later history-⁰¹, a subsequent uplift resulting in its excavation and in the capture and diversion of neighbouring rivers²⁰³. The ridges of the Rockies are related to the underlying structure of the range, whereas those of the Selkirks²⁹⁴ are simply carved out of the uplifted peneplain. The Purcell Trench now corresponds in its middle part with the Kootenay Lake Valley, and the tilting of the peneplain seems to have been the primary cause for the flow of the parallel rivers southwards. The excavation of the valleys seems to have been effected in Tertiary and Quaternary times.

The whole Canadian Cordillera Rocky Mountain System may be regarded, broadly speaking, as divisible into two great geosynclines^{351 134} stretching along the whole Cordillera, and these overlap in the vicinity of the Columbia River. The eastern one is known as the Rocky Mountain geosynclinal³¹⁵ and the western one as the Pacific geosynclinal. The former lies between the great Plains and the Purcell Trench, and embraces sediments ranging in age from the Cambrian (base of Beltian) to the Carboniferous (Mississippian) inclusive ; throughout this long period there was practically continuous deposition marked by only minor interruptions. Younger and local geosynclinals of Jurassic, Cretaceous, and

Tertiary beds were laid down unconformably on this prism along its eastern border, and have their major axes parallel to it. The greatest interruption was caused by the crustal disturbance (the 'Laramide orogenic revolution') at the close of the Cretaceous. This whole eastern belt forming the foot-hills is characterised by open folds, fault-blocks, and over-thrusts^{365 576}, with moderate regional metamorphism and minor igneous activity.

The western or Pacific geosynclinal lies between the Purcell Trench and the Pacific Ocean, and has as its dominant formations a great thickness of Upper Carboniferous (Pennsylvanian), Triassic, and Cretaceous rocks, the Pennsylvanian being traceable from Alaska to southern California. Its earliest record begins with the Pre-Cambrian (Shuswap Series), which is exposed in a block between the two geosynclinals on the Canadian Pacific Railway⁵¹. But from the Pre-Cambrian until Lower Carboniferous (Mississippian) times the Pacific geosynclinal was an area of erosion. Then submergence took place accompanied by deposition, which was interrupted by the Upper Jurassic crustal disturbance or 'Nevadian orogenic revolution,' and it was followed (or immediately preceded and accompanied) by the intrusion of many huge batholiths of granodiorite and other igneous rocks, especially near the coast and parallel to it. The Cretaceous geosynclinals formed during a subsequent submergence were smaller and local. At the close of the Cretaceous there took place the 'Laramide revolution'; subsequently Tertiary non-marine sedimentation proceeded, but was interrupted by local folding, and was marked by long continued vulcanism. The intrusion of further batholiths occurred in Miocene times. This Pacific or western geosynclinal is characterised by close folding, mashing, and strong regional metamorphism, together with the development of batholithic intrusions and volcanic activity on an immense scale on repeated occasions³. There seems to be a special connection between the kinds of tectonic movement and the types of associated basic and ultrabasic rocks⁵⁵⁶.

The chief epochs of orogenic movements in the Cordilleran region are therefore seen to be the Pre-Cambrian, the Nevadian, and the Laramide, and it is particularly to the latter that the structural features of the Rocky Mountains must be ascribed. As a result of those disturbances in southern Alberta, we see the mountains chiefly composed of fault-blocks, often overthrust²⁶⁵ from west to east, with the back slopes more or less coinciding with the dip of the beds. The general structure of the Rockies is that of overfolds and faults parallel to the longitudinal trend of the ranges²⁶⁴, with over thrusts from the west.

The southern part of the Rocky Mountains is divisible structurally into three areas³¹⁴ longitudinally lying between the international

boundary and the Crow's Nest Pass. The western area is marked by a series of parallel normal faults. The central area is a great syncline of Pre-Cambrian strata²⁴¹ separated from the previous area by a great normal fault or zone of faults, but the eastern part of this syncline is thrust over Cretaceous rocks to the east by the so-called 'Lewis thrust'³⁸⁶, having an enormous displacement and traceable from Montana northwards for over 100 miles. It was apparently one of the latest effects of the Laramide revolution, and probably took place in Eocene times and at any rate before the deposition of the conglomerates of the Cypress Hills. The eastern structural area consists mainly of the foot-hills⁶⁷² of western Alberta: the rocks are Cretaceous, except for a few areas of Devonian-Carboniferous limestone in the Crow's Nest Pass^{262 367 415} and some Eocene beds near the eastern margin. It is marked by numerous, nearly parallel, reverse²⁶⁵ strike-faults or thrusts⁵⁷¹ running from north-west to south-east, or north-to-south, with a high angle of dip. A detailed description of the successive nappes in the Crow's Nest area has been given by Bethune⁵⁷¹. North of this area Dowling³¹⁵ has described the thrusts and fault-blocks, while along the Athabasca River³¹⁸ seven blocks of strata have been pushed one over the other affecting beds down to the Pre-Cambrian. But in northern Alberta we also meet with sharp asymmetrical anticlinal fault-blocks or overfolds not overthrust. North of the Liard River^{198 315}, on the west side of the Mackenzie River, the folding and displacements become less intense. We thus see that there is a considerable variation in the tectonic structures of the Rockies as they are traced along their course, and that on the whole the chief feature is not folding but faulting and thrust-planes^{264 265 571 576}.

The age of the formation of the Rocky Mountain System dates mainly from the Laramide orogeny, though at the close of the Jurassic¹⁹⁸ or during the Lower Cretaceous, earth-movements again had taken place. Warren²⁹⁴ maintains that the folding and faulting processes occurred at the beginning of the Oligocene and that the Selkirks antedate the Rockies, for the conglomerates in the Kootenay formation (Lower Cretaceous) in the Rockies point to the source of supply being the Selkirks, while the Oligocene conglomerates are similar to those in the Cypress Hills⁴⁴², which contain vertebrate remains and are undisturbed, and rest unconformably³¹⁴ on the Paskapoo (Eocene) beds of the foot-hills. It seems, therefore, that there were local as well as regional earth-movements concerned in the development of the Cordillera and that they did not all occur at the same period or act with the same intensity and effect in all areas.

The western coast-line of Canada is of a type completely different from that on the Atlantic side in consequence of the different geological history of the Cordilleran region. For here the continental

border is determined by the parallel longitudinal fold-ranges and faults constituting the Pacific type of coast. The existence of a network of fiords along the British Columbian coast^{311 371} is also a marked feature. The fiords which Gregory³⁷¹ held as due to faulting have been otherwise interpreted by Peacock³¹¹, who considers them as forming merely 'the lower parts of an immature valley-system developed during an erosion cycle which was initiated or rejuvenated by a regional uplift of several thousand feet in the Pliocene, interrupted by a regional subsidence of about 1600 ft. in late Pleistocene or early post-glacial times, which was followed by a recent uplift of about 600 ft.' All the fiords were greatly modified by ice-erosion during the Glacial Period. We may, however, suspect that the directions of the valleys were determined to some degree by the shattering of the western margin of the continent during Jurassic-Cretaceous times by strong earth-movements which also occurred again in early Tertiary times and led to the formation of a mass of faults having at least two different trends, thus producing lines of weakness along which subsequent erosion worked. Thus it is seen that the development of the fiord system of British Columbia is due to the combination of a fractured and uplifted platform along the continental margin dissected by stream erosion before Glacial times and subsequently by ice action and later affected by regional subsidence producing fiord basins, while longitudinal faults have contributed to the formation of the fringe of islands³¹¹.

In striking contrast to the successive disturbances which are so conspicuous in western Canada, we must note that no fold-movements have affected the central plains, while in eastern Canada the principal earth-movements were of Pre-Cambrian and late Ordovician (Taconic) date, with subsequent local disturbances in late Carboniferous or Permian time on a minor scale, and minor marine incursions. There is none of later date, and no widespread submergence has taken place since Palaeozoic times, but only warping of the surface.

The last great marine transgression which affected North America was in Cretaceous times, when the sea spread from the Gulf of Mexico to the Mackenzie River, dividing the continent into a western and an eastern portion, and depositing the beds which now form the central plains. The absence of any later marine deposits in the interior or over the Canadian 'shield,' or even in the Cordilleran Province except near its western margin, is a most noticeable feature.

From the foregoing remarks Canada is seen to fall into two main geological divisions, *i.e.* (1) an eastern portion comprising nearly two-thirds of the whole Dominion, which has remained a land-area since the end or middle of the Palaeozoic; and (2) a western portion in which, during Palaeozoic, Mesozoic, and Tertiary times, sedi-

mentation and igneous activity have built up a thick pile of marine and fresh-water or terrestrial deposits and where mountain-building has repeatedly been at work.

DETAILS OF THE STRATIGRAPHY

For convenience of treatment of these large areas Dawson's plan of subdividing them into smaller regions based on geological structure and physiographic characters is here followed^{1 74 195}. Their relation to the physiographic divisions recognised in the United States is necessarily close¹¹⁶.

(1) The Appalachian or Acadian Region⁵³⁴, consisting of the maritime Atlantic provinces with the Gaspé Peninsula, Newfoundland, and the south-eastern part of Quebec Province (*i.e.* south-east of the Champlain-Appalachian fault). This is the region of complicated geological structure, as above mentioned. The representatives of much of the Palaeozoic succession lie for the most part folded in between Pre-Cambrian ridges.

(2) The Lowlands of the St. Lawrence include the plains bordering the St. Lawrence River, extending with a varying width from Anticosti to Quebec city and Lake Huron, and embracing also the Ontario Peninsula, south-western Ontario, the Ottawa Palaeozoic basin, and the areas of flat-lying Palaeozoic beds in the province of Quebec.

(3) The Canadian Shield, the general characters and boundaries of which have been sufficiently described above. This is the area of greatest mineral wealth¹⁹⁵.

(4) The Interior Continental Plain, comprising the central belt of plains lying between the western margin of the Laurentian Plateau and the foot of the Rocky Mountains, and decreasing in width from the 49° parallel to the Arctic Ocean. The provinces of Manitoba, Saskatchewan, and Alberta occupy most of the surface of this plain.

(5) The Cordilleran Region, or great mountain belt extending from the foothills on the east of the Rockies, westwards to the Pacific Ocean, and embracing the greater part of British Columbia, the off-lying islands, and much of the Yukon.

(6) The Arctic Archipelago, north of the Canadian Shield, largely consisting of flat-lying Palaeozoic beds^{144 169 368 370 371 605 612 616} corresponding to beds of the St. Lawrence Lowlands on the south of the Shield, and resting unconformably on the Archaean basement.

After some general remarks on each stratigraphical system the detailed description of the development of the successive geological formations is here given separately for each of these regions, commencing with the Acadian region.

Archaean and Pre-Cambrian⁹

In spite of great differences of opinion^{6 40 42 141 149 176 221 375 474 490 497} with regard to the nomenclature⁶⁴³, succession, and correlation of the ancient crystalline and Pre-Cambrian rocks in Canada and in the United States¹⁴⁹, and the multitude of local names³⁰⁷ in use for the various groups of rocks with special classifications, and notwithstanding the confusion which has arisen from the use of the same terms in different senses, two main facts are now generally

recognised^{6 7 83}. The first fact is that in the area of the Canadian Shield there have been two great periods of disturbance and erosion which are now marked by widespread unconformities, and the second is that there have been two great irruptive periods during which batholiths of granite and gneiss invaded the earlier rocks. There is a general consensus of opinion with regard to the sequence of the principal formational groups⁴⁹⁷ and the position of the intervals of erosion. To the older series of batholiths⁵⁸⁹ of plutonic rocks the name *Laurentian* is applied, while the younger series of batholiths has been termed *Algoman*^{6 42}, and these designations are conveniently employed. The earlier of the periods of erosion is sometimes called the epi-Laurentian or pre-Huronian, since it follows the first irruptive period, but precedes the accumulation of the second group of formations, while to the second or later period of erosion the terms post-Algoman, or Eparchean, have been applied.

As a general rule, there is progressive metamorphism and disturbance from the youngest to the oldest formations of the Pre-Cambrian succession; thus the post-Algoman formations are comparatively little altered and lie flat or only slightly folded, while the pre-Algoman Timiskaming and Sudbury groups are more disturbed and altered, and the pre-Laurentian rocks have suffered excessive changes, being frequently highly crushed, folded, and contorted⁴⁷².

The local development of the Archaean and Pre-Cambrian varies considerably, and local names are legion⁶⁴⁸; in many parts the absence of certain of the members of the full sequence renders the correlation a matter of dispute⁴⁹⁰. The most favourable regions for establishing a standard scale for reference are those in Ontario and western Quebec around Lake Superior^{6 332} or around Lake Huron^{7 196 375 497}.

The fullest development of the Archaean and Pre-Cambrian succession is on the Canadian Shield. Local classification of the formations with local names in widely-separated areas is unavoidable in the present state of our knowledge. In the Report of the National Committee in Canada on stratigraphical nomenclature in 1934³⁷⁵ the term Archaean is used to denote the lower division of the Pre-Cambrian, while the Upper division is termed the Proterozoic, which is apparently synonymous with the British usage of the term Pre-Cambrian; the whole pre-Palaeozoic succession is thus given in a generalised form:—



The Upper Laurentian period covers the intrusion of the Laurentian granite and the subsequent erosion, and the Upper Timiskamian that of the intrusion of the Algoman granite and the subsequent erosion and production of the main great unconformity between the Archaean and Proterozoic. The general features of the Archaean sedimentation have been described by Pettijohn⁶⁵⁸. The most complete and well-established succession of the whole Pre-Cambrian is found in Ontario. The names and development of the various local formations during these periods are given below in the accounts of the different regions. In the following descriptions the term Pre-Cambrian is used in the British sense as throughout this book. Two main orogenic periods occurred during the Archaean-Pre-Cambrian. The first orogenic period occurred after the

intrusion of the Laurentian igneous rocks, and was succeeded by long and extensive erosion of the surface. The second orogenic period was after the intrusion of the Algonian irruptives and was likewise followed by a long period of peneplanation constituting the *Eparchæan interval*⁵⁵². The age relations of the intrusive rocks have been estimated by the helium method in the Red Lake district⁵⁸¹, Ontario, and three periods of magmatic activity have there been recognised, the first early pre-Algonian, the second late pre-Algonian, and the third Algonian.

1. THE ACADIAN REGION⁵³⁴.—The Archaean and Pre-Cambrian rocks of this region consist partly of metamorphosed sediments, and partly of altered volcanics, but are all intruded by plutonic masses varying in composition from gabbro to granite, and differing considerably in age. The metamorphosed sediments of Palaeozoic age frequently possess intricate relations with these intrusives, and in the similarity of the superinduced lithological characters and the absence of fossils, are separated from them with great difficulty. There is consequently considerable difference of opinion with regard to the age and correlation of the schists and gneisses, and even of some of the less altered rocks. The chief areas in which Pre-Cambrian rocks occur in the maritime provinces are in northern New Brunswick and in the island of Cape Breton, and near the Bay of Fundy in southern New Brunswick. Nova Scotia has another large area of Pre-Cambrian rocks under the name of the 'Gold-bearing Series.'

In the eastern townships of **Quebec** the Pre-Cambrian appears in narrow belts running from N.E. to S.W., and is mostly of volcanic origin, belonging to the quartz-porphry and andesite series, but changed into schists. The Sutton Mountain is the extension in eastern Quebec of the Green Mountains of Vermont, and the range again appears in the peninsula of Gaspé^{261 281}. Western Quebec belongs to the Canadian Shield (*q.v.*).

In **Cape Breton** there is a great felsitic series, and masses of crystalline limestone are said to overlie it unconformably¹⁴³. Schistose rocks of possibly sedimentary origin and quartzites are interbedded with these limestones, and intrusive granites, gneisses, etc., which are younger than this metamorphic series, but are probably partly Pre-Cambrian³³ in age, are associated. The upland districts of Cape Breton³³⁷ are chiefly occupied by quartzites and limestones (often metamorphosed), forming the *George River Series* which is invaded by masses of plutonic intrusives, especially granites and diorites. The so-called 'Coldbrookian' of Matthew, which consists of lava-flows, tuffs, and conglomerates, is referred by some authors to the Pre-Cambrian instead of to the early Cambrian.

In southern **New Brunswick**^{268 290} crystalline limestones, quartzites, schists, slates, and greywackes seem to fall into several groups separated by unconformities or periods of igneous intrusion, and embracing various petrological types^{9 188}. Hayes and Howell²⁹⁰ have recently made a detailed examination of the St. John district, and here they call the lower (or Laurentian ?) series of plutonic intrusives (gneiss, granites, gabbros, diorites) the *Golden Grove Formation*; its age can only be stated as pre-Carboniferous, but it invades the Pre-Cambrian folded rocks which are named the *Green Head Series*, consisting of altered sedimentaries (limestones, dolomites, quartzites). An Upper Volcanic group of rocks, the *St. John Volcanic Series*, is composed of tuffs and **breccias** with subordinate lava-flows mostly of an acid nature.

In **Nova Scotia**^{4 4a} the 'Gold-bearing or Megurna Series'³²⁷ of rocks is of Pre-Cambrian age, according to Van Hise, Walcott, and Matthew, and extends

along the whole Atlantic coast of the province, but not into Cape Breton Island. It covers an area of 10,000 square miles, and consists of sedimentary rocks reaching an estimated thickness of 35,000 to 38,000 feet. The series is composed of quartzites and slates, apparently conformable; the beds are closely folded into a succession of long parallel anticlines and synclines and dome-shaped folds with the axes pitching east and west. The beds are much faulted and cleaved. The gold-bearing quartz-veins are mostly interbedded, and occur as successive saddle-reefs, chiefly on the domes of the anticlines. But they are regarded as epigenetic and formed during the folding of the strata. Granite batholiths (probably Devonian) cut the folds, as on the coast at Halifax, and alter the surrounding rocks, so that metamorphic schists and gneisses surround the granite masses. Basic dykes and sills also occur. The sedimentary series is divisible into a lower portion (*Goldenville Formation*) composed of thick-bedded, compact, greenish-grey quartzites, with argillaceous slates 15,000-23,000 ft. thick, and an upper (*Halifax Formation*) of argillaceous and siliceous slates, with a siliceous limestone at the base, 11,700 ft. thick²⁶⁷.

In some places (*e.g.* Queen's County)¹⁴⁶ there are highly crystalline and metamorphosed sedimentaries which probably belong to the same series; they comprise quartzites, mica-schists, and gneisses, and are greatly contorted and penetrated by intrusive granite.

In **Newfoundland**^{97 181 249 255 289 470 531} the so-called 'Laurentian' granites and gneisses, with occasional bands of limestone and anorthosite intrusions, form broad bands stretching from north-north-east or north-east to south-south-west or south-west, and constitute the principal mountain ranges, with a few inselbergs⁶²⁵. Between these bands lie Pre-Cambrian sedimentary rocks, with basic volcanics and various intrusives. The sedimentary members (forming the so-called *Avalon Group* from its great development in the peninsula of Avalon)¹⁶⁸ consist of quartzites, slate-conglomerates, slates, and sandstones, gently folded, and have yielded the problematical fossil *Aspidella terranova*. In the lower part of the group basic and acid volcanics¹⁸¹ have a large development. The total thickness is estimated at 11,000 ft. (Murray); Van Hise⁹ correlates this group with his Algonkian, and believes that it is probably equivalent to the Gold-bearing Series of Nova Scotia.

2. The CANADIAN SHIELD⁴⁹⁷, with its area of nearly two million square miles, affords evidence of a long and complicated history, and gives the fullest record of events in Archaean and Pre-Cambrian times^{42 387 472-474 495 497 589 634}.

In **Labrador**¹⁹⁷ the north-eastern coast^{434 471 489 502 604} marks the edge of the great Archaean 'shield' and crystalline rocks (gneisses, schists, intrusive granites, gabbros, etc.) prevail from the Straits northwards to Cape Chidley. But stratified sedimentary beds, including conglomerates, sandstones, quartzites, slates, and intercalated traps, rest unconformably upon them at various places (*e.g.* Cape Mugford and Raman)⁴⁷¹. The granites and gneisses mostly resemble those of Ontario referred to the Laurentian, and include patches of possibly Keewatin rocks. There are also probable representatives of the Grenville^{434 489}, Timiskaming, or Sudbury Series of the Canadian Shield (see below). All these are invaded by numerous dykes of diabase or dolerite. The stratified rocks, which lie unconformably on the gneisses, etc. and are not invaded by the dykes, consist of slates, quartzites, arkoses, and dolomites, usually with a low dip or folded; they constitute the *Ramah series*^{434 489}. Another isolated group of rocks, consisting of sills of diabase, tuffs, and agglomerates (the *Mugford Series*), may be of Animikie or Keweenaw age. All are apparently Pre-Cambrian. The Kaumajet Mountains⁶⁹⁴ in northern Labrador consist of basaltic lavas and ashes, peridotite, etc., with much

trachytic tuff, according to Odell⁶⁰⁴, cut by basic dykes, and may be regarded as late (? Keweenaw) Pre-Cambrian in-age. The beds lie more or less horizontal on the basement (Archaean) gneiss. There appears to be a parallelism of the structural trend and the coast-line, and this extends still farther north-west.

Arctic Regions.—In the Cumberland Sound region and Foxe Land of Baffin Island⁸⁷⁰ all the rocks are acid intrusives, including several types of granite, quartz-diorite, granite-porphyry, aplite, monzonite, etc. Whether these belong to the Laurentian or Algonian intrusive episodes or partly to one and partly to the other is undetermined. Gneisses also of various types and of uncertain correlation form the foundation of the Ordovician beds which succeed them with a great unconformity.

Quebec and Ontario.—The so-called ' *Fundamental* ' or ' *Laurentian* ' Gneiss extends over wide areas in the provinces of Quebec⁴³⁸ and Ontario, and consists largely of igneous rocks, some banded and foliated. These are penetrated by huge masses of anorthosite and other intrusives⁵⁸⁹, of which the Morin anorthosite²⁷ mass, 30 miles north of Montreal, is an example. Labradorite in its iridescent variety is abundant in these rocks.

Closely associated with the Fundamental Gneiss, and overlying it but penetrated by it, is the *Grenville Series*^{216 288 595} of sedimentary rocks in Quebec and parts of Ontario. This *Grenville Series*, which Logan included in his Laurentian Formation, together with the Keewatin and Couchiching Series (see below), comprises the earliest known formations in Canada and constitutes the Lower Laurentian; it consists chiefly of limestones with some quartzites and conglomerates, and has been studied in detail in the Haliburton-Bancroft area near the southern margin of the Canadian Shield^{5 12 216 273 288 487}. It has been estimated to extend over 83,000 sq. miles. It has an eruptive contact with the gneissic granite²⁷³—the so-called *Laurentian*—the latter having invaded and shattered these sedimentary rocks, and included large masses and strips of them. The great lenticular or rounded bosses or batholiths of granite and granite-gneiss themselves possess a more or less distinct internal foliation which is seen to conform in general to the strike of the invaded rocks, but it bends concentrically round within the area of the separate batholiths in closed curves, and the planes of foliation dip outwards (rarely inwards) on all sides. This structure has been produced by movements in the granite itself while molten. There are all stages from foliated to massive varieties⁴⁷³.

The limestones⁴⁸⁷ of the Grenville Series have in some places been comparatively unaltered, but in others pass into coarsely crystalline white marble, with many secondary minerals. The other sedimentary rocks have been altered into gneisses (para-gneisses). Intrusive⁶⁸⁹ gabbros, diorites, and nepheline-syenites also occur. But intimately associated with all these various types are amphibolite rocks, which may occur either interbedded with the limestones, or as horizontal modifications of the sedimentary gneisses, or as masses and strips included in the granite gneiss. They seem to have resulted in some cases from the alteration and recrystallisation of sediments, and as such occur interbedded with the limestones, but in other cases represent intrusive⁶⁶⁸ igneous rocks which have suffered complete recrystallisation, or are highly metamorphosed volcanic ashes and lava-flows. The amphibolite rocks may occur in the granite as very numerous scattered fragments, but often have been drawn out into streaks and strips in the direction of movement of the flow, so as to give it a banded appearance; in many cases they have been largely re-fused⁶⁶⁴.

The nepheline and alkali syenites^{139 663 664} occur in close genetic connection

with the granites, and seem to be a peripheral differential phase thereof. They are often rich in alumina which has crystallised out as corundum. Apatite also occurs at Kingston in veins in connection with pyroxenite intrusions in the Grenville Series.

The Grenville Series is estimated to have a thickness of 94,000 ft., and is one of the thickest pre-Palaeozoic sediments on the Continent, the thickness of limestone being unique. It is more or less continuously exposed over an area of 83,000 sq. miles in eastern Canada and the State of New York²¹⁶. The problematical fossil or inorganic structure known as *Eozoon* occurs in the Grenville limestones, near Ottawa, and Ontario has furnished some of the best specimens. In the Arnprior-Quyon area²⁷⁸ of Quebec the *Grenville Series*, consisting of limestones, mica-schists, quartzites, etc., is associated with rhyolites, andesites, and other volcanics which are thought to be contemporaneous lava-flows. The so-called *Bristol Series* in the same area seems to be only less metamorphosed Grenville beds, but may be of later date. In the western part of the Grenville sub-province²¹⁶ there is the *Hastings Series*, composed of conglomerates, limestones, argillites, etc., which is stated to overlie unconformably the Grenville Series. But the *Buckingham Series*, which is conspicuous in the Laurentian highlands of Quebec and consists of gabbro, diorite, syenite, etc., is intrusive⁵⁸⁹ into the Grenville, while great batholiths of granite and syenite, which are apparently later than the Buckingham Series, likewise invade the Grenville^{273 589}.

In the Abitibi district^{126 187 436} and Timiskaming County¹⁷⁰, Quebec⁴⁴⁶, there has been recognised (1) an older complex followed by (2) the Timiskaming Group, and (3) the Cobalt Series and the Keweenaw an intrusives. (1) The older complex consists of two main divisions, the *Abitibi Group* and the batholithic granite and gneiss (Laurentian). The volcanic rocks which constitute the bulk of the Abitibi Group, when traced into the Timiskaming region, are there termed the *Keewatin Series* (see below), and consist of basic and acid lava-flows, usually more or less metamorphosed, and commonly exhibiting amygdaloidal, variolitic, pillow, and other characteristic structures. A ferruginous dolomite which sometimes bears chrome-mica, and has been probably derived from an aplite or some intrusive, is also remarkable. This series is invaded by the above-mentioned batholiths and smaller masses of granite and gneiss constituting the Laurentian.

The Rouyn-Harricanaw region^{328 446} and the Lake Chibougamau area³⁴², Quebec, have the *Keewatin* represented by highly-altered lava-flows of intermediate composition, with coarse fragmentals, but there are also felspathic sediments and acid volcanics (dacites and trachytes). There are ultrabasic, basic, and acid intrusives in the Chibougamau area, ranging from serpentines to granites, and forming a special feature. A later and little metamorphosed sedimentary series, of which only remnants occur, may represent the Cobalt Series, which belongs to the Huronian Series (*q.v.*). It is maintained by some geologists⁴⁴⁶ that in the Rouyn-Harricanaw area no division can be drawn between the Keewatin and Timiskaming formations, whatever may be the case in other areas. The boundary between the Keewatin and Timiskaming is normally an unconformity, according to Moore⁵⁰⁶, and marks the break between the Archaean and Pre-Cambrian.

Farther west in Ontario, in the Lake of the Woods and Rainy Lake district⁸, precisely similar relations to those in Quebec are found existing between the Laurentian and the overlying rocks, an irruptive contact being again present. These overlying rocks are here divided into two series, the *Couchiching Series*^{251 483 488} below, and *Keewatin Series* above. The *Couchiching Series*⁴⁸⁸ consists chiefly of altered sedimentary rocks, mica- or quartz-schists, without limestones or volcanic rocks or conglomerates. They are distinctly

bedded and have a total thickness of 20,000 ft. The *Keewatin Series*, in their typical locality of the Lake of the Woods⁸, comprises black or greenish hornblendic and chloritic schists, altered lavas and ashes, tuffs, agglomerates, felsitic schists (quartz-porphyrries and their tuffs), and conglomerates with granite boulders, etc. The rocks, which are sheared to a variable extent and generally schistose, are chiefly volcanic in origin. In northern Quebec⁵⁹⁵ there is a thick series of sedimentary beds intercalated in the Keewatin, and such is also the case in other parts of that Province³⁴². There is no evidence that the Coutchichings were disturbed or eroded before the pouring out of the Keewatin lavas over them.

The underlying, but later, *Laurentian* is intrusive and consists of granites, granodiorite, biotite-gneisses, hornblende-gneisses, syenite-gneiss, and granitic gneiss; it contains angular fragments of the Keewatin and Coutchiching rocks more or less fused and absorbed, and often drawn out into strips or bands just as in the case of the Grenville Series and associated rocks. This structural relation of the Laurentian to the overlying rocks probably persists throughout the whole of the pro taxis. Van Hise regards it as a case of ordinary igneous intrusion, but it has been suggested that the Laurentian is the result of the fusion of the original floor on which the overlying rocks were deposited. However, no trace has ever been definitely found of the unfused floor. It is estimated that the Laurentian covers probably more than 1,000,000 sq. miles of the Canadian Shield.

The *Keewatin Series*⁸⁴ is also very widely developed in western Quebec³²⁸ 342 505 and in northern Ontario, as near Cobalt and Lakes Timiskaming and Timigami. It is generally characterised by the 'iron-formation'^{88 235-237}, which is typically developed in the Vermilion district, Minnesota, and contains beds banded grey and black with silica and magnetite, or red and bluish grey with jasper and haematite. This iron formation seems absent from the Rainy Lake district, but is extensively developed in the Nipigon district¹⁰⁹, and in the Michipicoten district^{222 235-585} and Thunder Bay area³³². There are also arkoses and slates in the series, the sedimentary facies being the normal development and the accompanying volcanics⁶⁵⁹ being more or less accidental. Schists of the Coutchiching type are also widely spread in northern Ontario⁸⁴. In the Matachewan district the Keewatin includes rhyolites, andesites, basalts, and their associated tuffs. All are invaded by bosses of granite and by later dykes of diabase. The Keewatin Series contains many gold-deposits and veins in Ontario and Quebec (see 'Economic Geology'). On the Bell River in Quebec³⁸³ there is an igneous complex of intrusions resembling the Bushveld complex of South Africa.

In the Birch-Slate Lakes district⁵⁵⁰ of north-west Ontario the Keewatin volcanic rocks are underlain by a series of sedimentary beds as well as succeeded by sedimentary rocks. The lower series probably corresponds with the Coutchiching Formation.

With regard to the equivalence of the Keewatin and Grenville Formations, Miller and Knight⁴² held that the Keewatin rocks mostly represent submarine lava-flows upon which the Grenville sediments were deposited, but that part of the latter were contemporaneous with the volcanic eruptions. The Grenville is now found mainly in south-eastern Ontario, and the adjacent parts of Quebec; in the northern and north-western parts it was largely eroded, especially before the deposition of the succeeding series (Sudbury Series), and hence is there mostly absent. The Coutchiching Series is regarded by the same authors as equivalent to the basal part of the Grenville, and they maintain that the name should be discarded.

With regard to the age, relations, and nomenclature of the **formations of post-Laurentian date**, which occur in Ontario and Quebec in **the Canadian**

protaxis, there are differences of opinion, and well-known and old-established names are employed in different ways by various geologists^{6 7 42 187196 221}. This is especially the case with regard to the name *Huronian*, which Logan in 1863 intended⁷ to include all the pre-Cambrian sediments and eruptives above the Grenville Series and the Laurentian granites and gneisses, but below the Animikie Series^{382 497 552}. But some geologists (Lawson⁶) apply the name Huronian to the formations between the Laurentian and Aigoman irruptive periods, while others (Coleman^{7 316} and Collins⁸⁷) apply it only to post-Aigoman formations above the 'Eparchean' interval⁶⁶². Miller and Knight⁴² would discard the name altogether.

Van Hise and Leith⁸⁸ in the Lake Superior region refer the Keewatin and Laurentian to the Archaean, and all the other formations they place in their Algonkian Group, which they divide into the Lower, Middle, and Upper Huronian and the Keweenawan Formations.

The names of the principal stratigraphical divisions of the post-Laurentian formations as suggested by the National Committee³⁷⁵ in 1934 have already been given, but further details are necessary here. The Lower Timiskaming period embraces the deposition of the Timiskaming Series, and the Sudbury Series (see below). The Lower Huronian is marked by the Bruce Series. The Cobalt Series is referred to the Upper Huronian, and the Animikie Series to the Lower Keweenawan. The Upper Keweenawan consists of volcanic rocks, with a few sedimentaries; the Killarney granite, the Nipissing diabase, and Sudbury irruptive belong to this stage.

The 'Timiskaming Series'¹²³ of the Cobalt, Porcupine, and Kirkland Lake areas is a continuation of the Sudbury Series, to the north and east, and has the same relations and general characters. The *Sudbury Series*⁶⁵² constitutes part of the Lower Timiskamian, and is believed to pass into the Timiskaming Series as a laterally different development. Coleman^{7 7a} included in it somewhat more beds than are now recognised. According to Collins²⁸⁴ there was continuous deposition between the Keewatin and Sudbury Series, with generally a complicated alternation of volcanics and sediments forming a zone of transition. Collins²⁸⁴ describes it as developed in three areas near Ramsay Lake and Lake Panache, and its most characteristic rock as a grey-green argillite or greywacke with alternations of quartzite; conglomerates are rare. The main belt of the series has a probable thickness of about 7000 ft. There are no volcanic rocks in it. The eastward extension of the Timiskaming Series⁵⁰⁵ to Larder Lake^{187 397} and 100 miles beyond it in Quebec has been called the *Pontiac Series*; it overlies the Keewatin Series unconformably and is intruded by masses of granite and other igneous rocks (Aigoman intrusion). There is an interesting occurrence of varved slates⁴⁷⁷ in the Abram Series (Timiskamian-Sudburian) of north-west Ontario similar to those found in Finland, and suggesting annual or periodic climatic alternations of sedimentation⁶³³. Conglomerates of supposed glacial origin have been described from various places in this series as in the Porcupine area. After the deposition of the Sudbury-Timiskaming Series there was another invasion of granite and gneiss known as the *Aigoman*, or *Lorraine, Granite*. The Aigoman intrusives include many petrological species, and a considerable variety is found in the Matachewan-Kenogami⁵⁸⁶ and Rowan-Straw Lakes⁵⁸⁸ areas in Ontario, where the Keewatin volcanics are also well developed. In the Rainy Lake district the basal group of rocks, consisting of green schists, volcanic ashes, dolomitic limestones and conglomerate, resting directly on the Keewatin, is known as the *Steeprock Series*³⁸⁶, and is succeeded by the *Seine Series*³⁷⁹ of quartzites and slates, deposited prior to the Aigoman intrusions.

A long period of erosion (post-Aigoman) followed these intrusions, and after

it there began the accumulation of formations referred to the Huronian³⁷⁵. The Lower Huronian is represented by the *Bruce Series*^{229 598}, which is well developed at the Shawinigan Falls⁵⁴³, on the St. Maurice River, Quebec, and consists of white quartzites with some conglomerate and limestone. It is succeeded unconformably by the *Cobalt Series*^{22 39 170 183 187 196 582 596}, marking the Upper Huronian (by some termed the Gowganda Series⁵⁸⁷), which has at its base a coarse boulder conglomerate or tillite (the *Ramsay Lake Conglomerate*^{7 284}) containing striated stones, many from distant sources, and is stated to possess all the characters of a glacial boulder clay or tillite; the matrix is of greywacke, and in it are imbedded angular, sub-angular, and rounded boulders of granite, quartzite, and other rocks of all sizes up to several feet in diameter. But according to some geologists the characters of this deposit indicate stream-origin, and the striated pebbles as due to crush-movements in the rocks. Bain⁵⁷⁴ regards it as an alluvial fan deposit. It is generally considered to be a definite glacial deposit of the nature of a boulder-clay, and it is followed by thick white or red quartzites, including the peculiar jasper conglomerate of red pebbles, often sub-angular, in a white ground. Cherty limestone and more white quartzite complete the series, which reaches 12,000 ft. in thickness north of Lake Huron. The conglomerate extends all across northern Ontario for 1000 miles; it contains boulders of the Algoman granite and of the folded Timiskaming Series. The Cobalt Series³⁹ usually rests with a great unconformity directly on the Keewatin, and lies on a nearly level surface of erosion. The rest of the Cobalt Series in the Cobalt area consists of greywackes, argillites, arkoses, quartzites, and conglomerates, and has local unconformities between the beds, which are believed to be all of normal fluvial origin. The formation is said to cover 40,000 sq. miles.

In the Lake Huron district^{9 196}, the classical area for the typical Huronian Formation, there is a great development of these Pre-Cambrian rocks in the region between the Lake and James Bay. The quartzites and jasper-conglomerates of the upper portion (= 'Middle Huronian' of Van Hise⁵) have a close resemblance⁴² to the upper part of the Cobalt Series. In this region also the 'Huronian' rests unconformably on the greenstones and green schists of the Keewatin Formation, or upon the Laurentian granite and gneiss; Collins¹⁹⁶ describes its development on the north shore of Lake Huron.

The *Dote Series*³⁰¹, which is in some places 8000 ft. thick and includes a conglomerate, is developed in the Michipicoten area^{222 235 565}, and is put by some on the same horizon as the Cobalt Series or Upper Huronian; this conglomerate is likewise considered to be of glacial origin. The series rests unconformably on the Keewatin, as is usual.

The *Animikie Series*, which is often⁸⁸ put as part of the Upper Huronian, or is kept separate⁷, is included in the Lower Keweenaw by the National Committee⁸⁷⁶. As it has a considerable unconformity below it coinciding with a great transgression over the Canadian Shield, it seems best to follow Coleman and Parks in keeping it distinct from the other formations. In the United States it comprises the famous Marquette iron-bearing formation, but the iron-bearing^{222 235 237} and quartzitic members are not so well developed on the Canadian side of the lake. In the Thunder Bay region of Lake Superior³³² the formation is represented, and it is also developed around the Great Slave Lake⁴⁹⁷ and elsewhere. In the Sudbury basin it is known as the *Whitewater Series*, and Barlow²⁸ and Coleman⁷ termed it the Upper Huronian. It here consists of a boulder-conglomerate succeeded by volcanic tuff, black carbonaceous slates, and sandstones with a total thickness of 9400 ft.

The *Keweenaw*^{185 482} or *Nipigon Series* (=Upper Keweenaw³⁷⁵) overlies the Animikie Formation everywhere north and west of Lake Superior⁴⁷⁴, and north of Lake Huron^{196 221} with a considerable unconformity, pointing to an intervening period of elevation and erosion. It consists partly of sedimentary rocks, but chiefly of igneous rocks, comprising basic and less frequently acid lava-flows and plutonic intrusions, together with large numbers of sills and dykes of basic rocks^{216 426}. The rocks are hardly metamorphosed at all. Their maximum thickness for the Montreal River section has been estimated at 45,000 ft. The volcanic portion has a thickness of over 11,000 ft. on Michipicoten Island, and of over 16,000 ft. at the east end of the Lakes. The sedimentaries include conglomerates, sandstones, and some calcareous beds; the plutonic intrusions comprise gabbros, diabases^{298 426}, anorthositic, granites, etc. Valuable deposits of native copper (see below) and silver²⁹⁸ are found with the amygdaloidal lavas and other rocks. The great series of parallel dykes of diabase, which traverse the older Pre-Cambrian rocks in southern Quebec and south-east Ontario in a zone over 100 miles in length, is probably of late Pre-Cambrian (Keweenawan) age, and at any rate are pre-Potsdam²¹⁶.

In the Sudbury district the Keweenaw is represented by the famous nickel-bearing eruptive^{7a 70 86 90 174 185 258 284 301_303 500 564} which underlies the upper sedimentary beds of the Animikie, though it is of later date, and behaves as an intrusive laccolitic sheet. It is of huge size, for it occupies a boat-shaped basin measuring 36 miles in length and over 16 miles in width⁸⁶ into it the rocks have been bent by collapse of their central support. Petrologically it consists of norite on its lower side, passing gradually upwards into micropegmatite; blebs of ore are often scattered thickly through the lower part of the norite. Where there is a depression in the floor, the pyrrhotite-bearing norite merges into massive ore-bodies containing millions of tons of solid pyrrhotite and other sulphides. The pyrrhotite contains subordinate quantities of pentlandite (NiFeS) and chalcopyrite. By some geologists the ore deposits⁵⁰⁰ are regarded as the result of magmatic separation, but by others as deposited by heated waters. There are other intrusive igneous rocks of earlier and later age in the area, the former comprising gabbros, and the latter granites⁹⁰. Yates⁸⁰² considers that the intrusion of the norite was followed by intrusion of granite and later by dykes of various petrological types²¹⁶. The determination of the age of the Keweenaw by the helium method has been attempted by Lane and Urry⁴⁸². The older (pre-Huronian) rocks of the Sudbury district have been recently described by Cooke⁶⁵². The final important Pre-Cambrian event in this district was the injection of great olivine diabase dykes²¹⁶, which intersect every other rock in the Sudbury basin.

In the Cobalt area the so-called *Nipissing diabase*—a sill which passes into a micropegmatite or granophyre from a quartz-norite—belongs to the same period of igneous activity. It covers an area of about 5000 sq. miles, and has a thickness of 500-600 ft. (about 1100 ft. according to Whitehead¹⁸⁴). It cuts the older rocks in a 'plunging and arching sill,' but in the Cobalt area it is chiefly injected into the Cobalt Series. The silver-bearing veins^{183 184 298}
⁵²⁰ 582 mostly occupy vertical fissures in the Cobalt and Keewatin Series, and in the diabase (where they are richest and are predominantly due to replacement); they were apparently formed after the cooling of the sill and deformation of the area and fracture of the rocks by the rise of heated ore-bearing solutions, which deposited first cobalt-nickel-araenides, and then silver. The major folds of the district have axes trending north-east to south-west, and the great fault of the district, which, like all the others, is a reverse fault, runs parallel to them.

Similar silver-bearing veins with the same relations and history occur in the Gowganda and south Lorraine districts⁵⁰¹.

In the Porcupine area⁴⁹⁹ it has been suggested that the auriferous quartz - veins traversing the Timiskaming Series are of igneous origin, and are connected with the Lorraine, or with later granitic intrusions, being the final differentiation product of the acid magma, for they often resemble pegmatite dykes. The quartz contains liquid inclusions and gas-bubbles indicating its formation under great pressure, and the veins also contain in places the minerals feldspar, tourmaline, and scheelite.

On the **Belcher Islands** in Hudson Bay^{173 375}, representatives of the Animikie and Keweenaw formations of the Lake Superior region have been found. The iron-formation⁵⁷⁵ occupies large areas and is like that of the Mesabi Range on Lake Superior; the associated limestones are remarkable for consisting of large concretions of supposed algal origin.

Fossils^{168 388}.—With the exception of (a) certain primitive organisms occurring in limestones at Steeprock Lake^{89 379 386} in the Seine River area, which were named by Walcott^{388 547} *Atitokania*, and believed to be related to the *Archæocyathinae*, and (6) the possible algal concretions of the limestones on the Belcher Islands¹⁷³, no fossils have been discovered in these pre-Cambrian rocks, for (as stated above) *Eozoon*¹² is now regarded as an inorganic structure. The Steeprock limestones, which rest directly on the Keewatin in the Rainy Lake district, have been referred to the 'Lower Huronian,' and perhaps are on the same horizon as the limestones of the 'Lower Huronian' of Van Hise⁹, occurring on the northern shores of Lake Huron, which are separated by an unconformity from the jasper-conglomerates, etc., of the 'Middle Huronian' of that district, here referred to as bearing a close resemblance to the upper part of the Cobalt Series.

Metallogeny.—It has been shown by Miller and Knight^{42 42a} that there have been at least four great metallogenetic epochs during the Pre-Cambrian period in Ontario possessing a definite sequence and individual character of metal deposition. The Algoman and Keweenaw are characterised by metals other than iron, and no ore-deposits are known in the Laurentian.

3. INTERIOR CONTINENTAL PLAIN.—The Pre-Cambrian rocks on the boundary between **Manitoba** and **Saskatchewan**³⁴⁵ show many points of similarity in their development to the succession around Lake Superior and throughout Ontario. But a precise correlation is not at present attempted. Each area has its own special series of rocks to which local names have been attached, the development and character of the beds varying much, as the following examples show. In the Amisk Lake district^{171 366} the oldest rocks recognised are a basal series of volcanics, consisting of a complex of ancient surface lava-flows and fragmental rocks, with a few associated intrusives. The lavas are massive amygdaloidal greenstones showing pillow-structure. Some have been rendered schistose. Quartz-porphry dykes cut through these rocks, but are earlier than a complex of gneissic rocks, partly of sedimentary and partly of igneous origin. A batholith of granite-porphry also invades the volcanics. Two clearly sedimentary groups of rocks, consisting of conglomerates, quartzites, slates, etc., containing greenstone pebbles are of later date, and are invaded by granite-gneiss, which also is intruded into the volcanics. Large masses of granite of various types have finally forced their way into all the above-mentioned rocks, altering, and in places absorbing them; this granite is later than all the periods of pre-Palæozoic folding, but is prior to the Ordovician,

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In south-east Manitoba³³¹ the Pre-Cambrian is known as the *Rice Lake Series*^{5*4}. It consists of a series of andesites, basalts, rhyolites, and fragmental volcanic rocks (breccias and tuffs) invaded by many types of basic and acid intrusions (granites, gabbros, diabases, etc.) and succeeded with an angular unconformity by a series of quartzites termed the *San Antonio Series*. The correlation of these series with the other Pre-Cambrian rocks of the Canadian Shield is undetermined. In the Flinflon area, Manitoba^{326 548}, the *Missi Series*^{440 614} of conglomerates and greywackes rests on the *Wekuskvan* volcanics and has suffered progressive metamorphism as well as intrusion by later igneous rocks⁴⁴⁰.

In the Lake Athabasca area⁸⁴⁵ the Pre-Cambrian period is represented by sediments of at least three different periods of deposition which were separated by earth-movements and intrusion of various igneous rocks. The oldest group of sediments, known as the *Tazin Group*, consists of carbonate-rocks, quartzites, argillites, etc., all much altered into gneisses and schists. The second group of sedimentaries is of much the same character, but includes some iron formation. The third and highest group is known as the *Athabaska Series*, in which the dominant rock is a sandstone; it contains boulders of the older altered sediments and intrusives and may be correlated with the Keweenawan.

In the Great Bear Lake area^{355 364 481 511 549 638}, and the Great Slave Lake^{198 376 497} and Coppermine areas³⁶⁵, Archæan and Pre-Cambrian rocks occur, but the geology of these areas is not fully known. The Great Slave Lake Group⁴⁹⁷ resembles the Upper Huronian and has been thus correlated. The pitchblende deposits²⁹⁵ on Great Bear Lake^{364 637} occur in a complex of altered igneous and sedimentary rocks of Pre-Cambrian age (see 'Economic Geology.') In the district⁶⁵¹ between Gordon Lake and Great Slave Lake the early Pre-Cambrian rocks have suffered two stages of metamorphism and deformation before the deposition of the later Pre-Cambrian formations.

In the Mackenzie River basin^{178 198 317 835 592} the pre-Cambrian rocks have not been subdivided in much detail, but three groups have been so far recognised, the oldest consisting of highly metamorphosed schists, slates, limestones, quartzites, and volcanic rocks; the second group of intrusive granites or gneisses of probably more than one age; and the youngest group of not greatly disturbed sandstones, conglomerates, shales, limestones, and some associated volcanic rocks (basic) unconformably overlying both the other groups. The granites and gneisses cover the largest area.

4. CORDILLERAN REGION.—In this region³⁸⁹ the Pre-Cambrian rocks have a totally different development, and the formations have received many local names^{3 10 11 51 72}. They are frequently quite unaltered, and some indeed may have to be transferred to the Cambrian.

On the Bow River in Alberta^{10 51 99 241 385}, on the east side of the Rockies, there are over 5000 ft. of quite unaltered Pre-Cambrian sediments lying unconformably below the basal Cambrian conglomerate. The base of the series is not exposed, but the lowest beds (*Corral Creek Formation*) consist of quartzitic sandstones, and these are overlain by about 1300 ft. of purple, greenish, grey, and black shales (*Hector Formation*). The whole series is sometimes called the *Bow River Series*, but Walcott²⁴¹ called it the *Belt (Beltian) Series*⁴⁷⁸. In the Yellowhead Pass, Mount Robson district⁷⁸, a series of massive sandstones with interbedded siliceous shales, over 2000 ft. thick, was named by Walcott^{78 318 389} the *Miette Formation*, and regarded as comparable with the Hector and Corral Creek Formations of the Bow Valley¹⁰—and to belong to the Belt Series⁴⁷⁸ (see below).

In East Kootenay^{a 129 259} the so-called *Purcell Series*, which is probably Pre-Cambrian, but may include some Cambrian, and is estimated at about 24,000 ft. in thickness, has its lower portion chiefly composed of quartzites, its middle portion of limestones, and its upper of argillites, with flows of amygdaloidal basalt, tuffs, and intrusive sills²⁶⁹. A fossiliferous horizon³⁸⁸ with supposed examples of the crustacean *Beltina* has been found in the series. Another formation termed the *Windermere Series*^{232 326 340 357}, consisting of a basal conglomerate with overlying slates, quartzites, etc., rests unconformably on the *Purcell Series*²³² in the Windermere area, and in the Lardeau map area³²⁹ reaching from the north end of Kootenay Lake³⁵⁷ across the Selkirk Mountains to the Columbia River at Revelstoke, where similar late Pre-Cambrian rocks are better developed, and consist of several groups of beds with distinctive names. In the Slocan area^{39 340} the Windermere Series comprises schists, crystalline limestones, and gneiss. The Pre-Cambrian of the Salmo map area³³⁰ consists of limestones, schists, argillites, and quartzites invaded by batholiths of granite, diorite, monzonite, etc.

In the **Selkirk and Purcell Mountains** the Archaean and Pre-Cambrian are divided into two series, the *Belt Series* (or System) above, and the *Pre-Belt* or *Shuswap Series* or System below, supposed to be of Archaean age, separated by an unconformity. The *Shuswap Series*^{51 204 608} in the Selkirks consists of grey gneisses, hornblendic and micaceous, massive or schistose. But quartzites, limestones, schists, etc., also occur in the Series, which is over 29,000 ft. thick and extends northwards into the Yukon. The upper 10,000 ft. on Adams Lake consist of greenstone schists. The prevailing strike of the Shuswaps is N. 70° E., thus being nearly at right angles to the general Cordilleran strike. The beds are not seriously affected by orogenic folding, and over large areas are nearly horizontal; the series is less deformed than any of the overlying ones up to and including the Triassic⁵¹. Intrusive pre-Beltian granites are developed in places, but some may be post-Triassic. The Upper or *Belt Series*^{130 269} or System is over 30,000 ft. thick, and is composed largely of quartzites, metargillites, and limestones, the latter yielding remarkable algal fossils^{388 399 478 547 547a}. There are certain algal structures in the calcareous sediments of the Bahamas⁶⁷⁵ which bear a remarkable resemblance to members of the algal flora of the Belt Series, especially to the genus *Collenia* Walcott³⁸⁸. Walcott²⁴¹ divides this series in the Selkirks into an upper (*Glacier*) division (=Dawson's *Selkirk Series*) over 13,000 ft. thick, and a lower (*Albert Canyon*) division (=Dawson's *Kisconlith Series*) over 18,000 ft. thick. It is plainly a continuation northwards of the Belt System of Montana and Idaho⁴⁷³. The Glacier division passes up conformably into the Lower Cambrian, but on the Elk River in the Kootenay region an unconformity marked by a conglomerate separates the two systems⁴⁰⁰. It is therefore an open question whether some of the Beltian should be referred to the Cambrian rather than to the Pre-Cambrian⁴⁰⁰. In the Big Bend map area⁸⁵⁴ of the Columbia River in the northern part of the Selkirks the Pre-Cambrian much-altered rocks apparently belong to the Beltian Series or Purcell Series, and are invaded by granites of various types believed to belong to the general period of Mesozoic, post-Triassic intrusions, as in the Kootenay district. These rocks contain various mineral deposits of copper, lead-zinc and gold-quartz-veins. The northern part of the Selkirk Mountain Range³⁵⁴ is composed of altered Pre-Cambrian sedimentary rocks (mica-schists, gneisses, quartzites, argillites, crystalline limestones) with some altered lava-flows (greenstones) and intrusive igneous rocks (granites, etc.) of Mesozoic age. The rocks are much folded. In the Fraser River district the Pre-Cambrian, which is known as the *Cariboo Series*^{149 246 270 341 599}, consists of slates, quartzites, schists, argillites, and limestones, and is the source of the auriferous placer deposits.

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It directly underlies the Mississippian (Lower Carboniferous). In the Peace River Valley a series of mica schists⁸⁰⁰ are believed to represent the Cariboo Series. (Fig. 15, p. 375).

In the **Yukon district**⁹⁶¹⁰²¹⁰³ there is a considerable development of quartzites, gneisses, metamorphosed sediments, graphite schists, quartz-schists, and granite-gneiss, of which the last are intrusive and later than the rest. But the precise age and relations of all these rocks are in many cases doubtful. The whole succession of unfossiliferous pre-Cambrian rocks is known as the *Yukon Group*^{96 206 247 271 344 374 601 602} and apparently coincides with part or the whole of McConnell's 'Klondike Series.' Distinctive names have been given to the various local developments, but their correlation is uncertain. In the Whitehorse district²⁴⁷ the Pre-Cambrian is known as the *Mount Stevens Series*, and consists of sericitic and chloritic schists, limestones and altered volcanics.

Cambrian

General remarks.—The character of the floor on which the Palaeozoic formations of Canada were laid down after the great period of erosion which followed the Pre-Cambrian over the greater part of the Dominion has been studied by Baker⁶⁰⁹ and Lawson⁵⁵². Baker has drawn attention to the remarkable similarity of the unconformity between the Pre-Cambrian and the Palaeozoic and that between the pre-Pleistocene and the Glacial till.

(1) **ACADIAN REGION**¹⁴⁹.—Prior to the deposition of the Cambrian in this region there was a long period of crustal disturbance and folding accompanied by elevation and subsequent erosion⁵⁰⁹, so that a great unconformity separates the earliest Palaeozoic from the latest pre-Cambrian rocks.

In **New Brunswick**^{268 290} the whole series of Cambrian deposits is present^{142 290}, and is sometimes known as the St. John Formation¹⁴. The beds were laid down in four or five narrow troughs parallel to the Bay of Fundy¹⁸⁸. Matthew¹³⁶ separated off two basal groups as Coldbrookian and Etcheminian, but the former, which consists chiefly of volcanic materials, has been mentioned (p. 305) under the Pre-Cambrian, and the Etcheminian, which contains a brachiopod fauna, is held by Walcott to represent merely a phase of the Lower Cambrian. The whole Cambrian Formation is about 2900 ft. thick, and consists almost entirely of black shales and slates, with some quartzites, thin limestones, and conglomerates. A very rich fauna has been collected from it; *Protolenus* marks the lower beds; *Paradoxides* is found in the middle division, and *Lingulella* in the succeeding beds; while the highest beds contain *Parabolina*, *Peltura*, *Dictyonema*, etc., many of the species being those known in the Cambrian of Wales. In the St. John district the Cambrian has been divided up by Hayes and Howell²⁹⁰ into a whole succession of beds marked mostly by distinctive fossils. The name Etcheminian is by them restricted to the lowest beds. Ordovician beds follow on the Upper Cambrian. In the Chaleur Bay area³³⁶ the Upper Cambrian is present at one spot and has yielded a few fossils.

In **Cape Breton Island**^{33a 135 337} there is a closely similar succession and fauna, and, as in New Brunswick, the Upper Cambrian passes up gradually into the Ordovician, so that they were grouped together by Matthew under the name Bretonian.

In **Nova Scotia** the unfossiliferous Gold-bearing Series⁸²⁷, which has been above described (p. 305) as Pre-Cambrian, is often included in the Cambrian. It is overlain by shales, sandstones, limestones, etc., which are occasionally full of Upper Cambrian fossils.

In Newfoundland^{111 255} the Cambrian^{287 289 305 377 522 524 529 531 644} is well developed. The Lower or Georgian division (*Labrador Series*²⁸⁹) occurs as limestones, sandstones, shales, and quartzites, 1700 ft. thick, on the north-west coast and peninsula of Avalon, as well as on the opposite coast of Labrador. It contains numerous typical fossils (*Archceocyathus*, *Coscino-cyathus*, *Kutorgina cingulata*, *Olenellus thompsoni*, *Prototypus*, etc.). Schuchert and Dunbar²⁸⁹ have given a detailed description of the Cambrian in western Newfoundland along the Straits of Belle Isle, and divide the Labrador Series into three portions, the lower (the *Bradore Formation*) consisting of almost unfossiliferous sandstones. The middle portion of the Labrador Series is termed by them the *Forteau Formation*, and consists of shales and remarkable archaeocyathid reefs and sandy oolitic limestones. In Hawke Bay there is a series of limestones, sandstones, thin conglomerates, and quartzites about 250 ft. thick succeeding the Forteau Formation, and termed the *Hawke Bay Formation*; it contains *Cryptozoon*, *Olenellus*, *Paterina*. The Upper Cambrian is best known on the southern shore of Cape St. George, and is over 1100 ft. thick; it consists chiefly of dolomites and quartzites. The Middle Cambrian has not been detected in this part. In Canada Bay^{624 531}, on the east coast of the northern peninsula of the Island, the Cambrian begins with a group of sandstones and conglomerates resting unconformably on the Pre-Cambrian rocks, and is succeeded by fossiliferous limestones and shales containing Lower Cambrian fossils similar to those in south-eastern Labrador and the Highlands of St. John²⁸⁹. Middle Cambrian beds are here present consisting of limestones with trilobites, but the Upper Cambrian is absent, a disconformity following the Middle Cambrian, which is succeeded by Lower Ordovician beds. The Middle Cambrian (Acadian) is seen in Trinity and Fortune Bays²⁴⁹ where, taken together with the Lower division, it has a thickness of just 6000 ft. The most important section is exposed in Manuel's Brook^{263 377}, Conception Bay, where the *Olenellus* zone is succeeded by the *Paradoxides* beds, and the faunas occur in an unbroken stratigraphical section. The *Paradoxides* beds at Manuel's Brook³⁷⁷, which consist of 234 ft. of hard greenish and grey shales with a few bands of nodular limestone overlaid by 68 ft. of softer grey and black shales with occasional lenses of limestone, contain three faunas characterised by different species of *Paradoxides*. The faunas closely correspond with those of Great Britain and Scandinavia, as well as with those in eastern America. Many Welsh species of trilobites are here present (*Paradoxides hicksi*, *P. davidis*, *Holocephalina inflata*, *Microdiscus punctatus*, etc.), as in New Brunswick, and the affinity of the faunas is very close²⁶³. The Upper Cambrian is also developed in Conception Bay²⁶⁸, and is fossiliferous. The ferruginous cherts of Notre Dame Bay⁸⁰⁵ are probably of Cambrian age. The Cambrian faunas of Newfoundland have been recently re-described in detail by Lochman²⁸⁷ and Howell^{377 522} (*q.v.* for references).

In Quebec^{149 150 390}, south of the St. Lawrence, a portion of the *Sillery Formation*, consisting of slates, sandstones, and conglomerates, represents part of the Cambrian, but for the most part it belongs to the Ordovician (see below). The conglomerates¹¹⁹ contain pebbles with Lower and Middle Cambrian fossils; Upper Cambrian fossils are also found in places, though the beds are mostly unfossiliferous. Lower Cambrian⁶⁷¹ trilobites occur towards the base of the formation. This zone of Cambro-Ordovician beds is almost continuous southwards from the extremity of the Gaspé Peninsula^{218 281} to the Vermont border, and covers a large part of eastern Quebec. Within this belt, nearly 600 miles long, the strata are usually intricately folded and faulted, and the volume of the beds, chiefly sandstones and slates, is very great, probably reaching a thickness of 5000 ft., and representing various

divisions of the Cambrian from the highest to the lowest. In southern Quebec³⁸⁰ a series of slates, quartzites, dolomites, greywackes, with chloritic and epidotic schists at the base, have been much folded and faulted and are referred by Clark³⁹⁰ to the Lower Cambrian. Some of the limestones and quartzites contain trilobites and brachiopods. Part of the *Levis Formation* in Quebec is of Cambrian age, and Clark and Rasetti⁶⁴⁹ have described a rich fauna from the *Levis Conglomerate*, many genera of trilobites being especially abundant, but Lower Ordovician species also occur in the *Levis Formation*⁶²⁶ (see below).

(2) In the LOWLANDS OF THE ST. LAWRENCE large areas are underlain by the *Potsdam Sandstone*¹³⁷ (Upper Cambrian) around the junction of the Ottawa and St. Lawrence Rivers. The beds are exposed along the eroded summit of a low broad dome, and were deposited along the shore of the old Pre-Cambrian land-mass in a sea connected to the south, but cut off on the east and north. The *Potsdam* is unknown above Quyon on the Ottawa River, and appears to be absent west of Kingston. East of Quebec it is also missing. In the Appalachians and centre of the United States this formation has a wide development, and is characterised by the trilobite *Dicellograptus*.

(3) CANADIAN SHIELD.—Various outliers of fossiliferous Cambrian rocks occur in Labrador, and others on the east and west sides of Hudson Bay, resting on the much-disturbed and eroded Pre-Cambrian and Archæan rocks.

(4) CORDILLERAN REGION^{12 15 16 51 75-78 99 224 349 372 389 392 491 533}.—The Cambrian is very fully and extensively developed in this region on both sides of the Rocky Mountains in Alberta and British Columbia, and attains a thickness of 18,000 ft. in the great trough of deposition, the Rocky Mountain geosyncline, which runs in a general north-and-south direction east of the Selkirk and Purcell Ranges. Some of the best sections in the world are here exhibited, as at Mounts Stephen, Bosworth, and Robson⁷⁸, and they have been studied in detail by Walcott²⁸⁹, who has described minutely the various sections and the fauna; Deiss³⁷² has given further details. The beds are unaltered, and nearly horizontal and undisturbed; they rest unconformably on the Pre-Cambrian. In the Mount Bosworth section^{16 372} over 12,000 ft. of strata are exposed, and they are divisible into Lower, Middle, and Upper Cambrian, with special local names for the successive formations.

In the Field and Banff³⁸⁵ areas the Cambrian forms a conformable series over 16,500 ft. thick⁹⁹. The lower beds are chiefly arenaceous, consisting of quartzitic sandstones and siliceous shales, but the middle and upper beds are mainly limestones, often very thick and massive, with subordinate shales. Here, in the Lower Cambrian, the Mount Whyte Formation^{76 349 372 389} contains *Olenellus* and several species of the trilobites *Corynexochus*, *Mesonacis*, and *Ptychoparia*, which are closely allied to species occurring in the Atlantic province, while several of the brachiopods are identical. But in the Middle Cambrian the fauna is distinct from that of eastern America, a feature especially marked in the case of the trilobites^{79 81}, which include species of *Olenoides*, *Ogygopsis*, *Neolenus*, *Oryctocephalus*, *Bathyriscus*, *Zacanthoides*, *Dorypyge*, *Burlingia*, *Albertella*⁷⁷, etc. Many Crustacea, merostomata, annelids, and holothurians in a remarkable state of preservation have been described by Walcott^{75 350}. Most of these fossils have been obtained from the *Mount Stephen Formation* (Middle Cambrian) of Mount Stephen^{15 79 872 889 891} and from the *Burgess Shale* near Field³⁵⁰. The Upper Cambrian consists chiefly of limestones.

The *Sawback Formation* near Banff^{335 389 392} is of Upper Cambrian age, and consists of limestones, dolomites, and shales, over 3000 ft. thick, and

yielding a few fossils. Walcott³⁸⁹ has recognised several subdivisions of this formation in the Lake Louise region, giving them special names.

In the Sinclair Canyon^{349 389} section of the Brisco-Stanford Ranges along the Columbia River there is a fine exposure of Cambrian, Ordovician, and Silurian fossiliferous beds measuring several thousand feet in thickness, which Walcott has described. In other parts along this river there is likewise a well-developed succession of Lower Palaeozoic beds. A fine Cambro-Ordovician section is exposed near Golden, B.C., in the Beaverfoot Range²²⁴. The Upper Cambrian fossils from the Brisco-Dogtooth map³⁵⁸ area have been described by Kobayashi³¹⁰, who also records the genera *Parabolinella* and *Glyptagnostus* from the 'Olenus beds'³⁵⁸ of Jubilee Mountain which are unexpected immigrants from the eastern palæogeographical province. In Jasper Park^{299 318 425 491} the Upper Cambrian is followed by the Ozarkian (=Tremadoc) and consists of shales and limestones with typical fossils. In the Sunwapta Pass⁴⁹¹, Jasper Park, Alberta, Middle Cambrian shales with the Mount Stephen fauna have been discovered. The Cambrian is believed to be represented in the Peace River area by the massive quartzites and calcareous shales of Mount Selwyn³⁰⁰.

In the Mount Robson section^{70 80 389}, where the basal sandstones of the Cambrian Series rest with an unconformity on the Miette Beltian Formation, the whole Cambrian Series has the same general lithological characters and succession as in the Mount Bosworth section, and is likewise over 12,000 ft. thick. The lower beds contain *Olenellus*, *Lingulella*, *Mickwitzia*, and other fossils³⁰. There is no well-defined lithological break between the Cambrian and the Ordovician in this locality, and there is a mixture of the faunas in the lowest Ordovician beds which succeed the Upper Cambrian. In the Mount Assiniboine region^{372 389} that mountain and Mount Wedgwood are composed of Lower and chiefly Middle Cambrian beds thrust over Devonian limestones.

In the Selkirk region^{3 400} there is no line of separation between the Beltian and the Lower Cambrian. A series of massive thick-bedded quartzites over 5000 ft. thick here belongs to the Lower Cambrian, and forms the highest points of the mountains.

On the forty-ninth parallel³, in the Clarke, Macdonald, and Galton Ranges and Purcell Mountains, there are thick series of quartzites, dolomitic limestones, etc., which bear many local names and are referred to the Cambrian. A thick sheet of basalt, 300-460 ft. thick, is associated with them. There seems to be an unconformity or disconformity between the Pre-Cambrian and Cambrian in the south-eastern part of British Columbia. Schofield⁴⁰⁰ holds that no orogenic movements took place in the interval, but that the Pre-Cambrian rocks are of continental origin, whereas the Lower Cambrian are marine.

The correlation of the various sections of the Cambrian in different parts of the Cordilleran area is not finally settled, but Deiss³⁷² has proposed a regional scheme for the Lower and Middle Cambrian. The Cordilleran geosyncline, which during the Palaeozoic extended from the Arctic to north-western Mexico and had the Canadian Shield as its eastern shore, was complex throughout all pre-Devonian times, having its floor divided into several troughs, each with a slightly different series of deposits. Between the 49th and 54th parallels, a distance of about 350 miles, three main troughs, the Bow, the Goodsir, and the Beaverfoot, have been described by Walcott^{241 389}. The Sawback trough was a minor one in the Bow trough, and all connected in the north with the Glacier Lake trough, while still farther north was the Robson trough. The time of their formation and their depth varied as well as the sedimentation.

In the Kootenay district the Cambrian is represented by calcareous grits, arenaceous limestone, and black shales (the Burton Formation) containing the *Albertella* fauna^{77 129}, which is regarded as transitional between the Lower and Middle Cambrian, and is present in the Mount Stephen section.

On the Yukon-Alaska boundary^{96 344} Middle Cambrian fossiliferous limestones occur, unconformably overlying a thick series of quartzites, limestones, shales, etc., which may be of Lower Cambrian or Pre-Cambrian age^{20*}. The Cambrian faunas of British Columbia have been described in detail by Walcott in many papers, and by Deiss³⁷², Kobayashi⁵³³, and others.

Arctic Archipelago⁶¹⁶.—The Palaeozoic beds which range from the Cambrian to the Carboniferous were deposited on the northern edges of the Canadian Shield simultaneously with those along its southern flanks in the Lowlands of the St. Lawrence and are mostly undisturbed and horizontal.

Distribution of Cambrian Faunas in North America¹⁷.—From the earliest Cambrian times there were four great oceans which, from time to time, invaded the continental area of North America; sometimes they were connected, and sometimes separated, while each brought in a more or less distinct fauna. These oceans may be termed the Atlantic, the Pacific, the Arctic, and the Gulf, from their approximate and relative positions. Three main land-elements also existed; in the west there was * Cascadia,' in the north the Laurentian Shield, and on the east the Appalachian-Acadian more or less continuous mass. Life-provinces, with more or less distinctive faunal characters, resulted from this distribution of land and water.

The Lower Cambrian seas lay in narrow synclinal troughs along both sides of the North American continent. At the close of the Lower Cambrian the first considerable post-Proterozoic crustal movement occurred, and a land-barrier was thrown up which completely prevented the later Cambrian faunas of the Pacific realm from passing into the Atlantic. Previous to this movement, the *Olenellus* biotas of the Pacific and Atlantic were very much alike, but as yet it is not precisely known where the channels of intercommunication existed. The two leading trilobites, *Olenellus* and *Hohnia*, are common to both regions, and the lists of fossils indicate that the faunas were cosmopolitan.

In Middle Cambrian times the sea over the Cordilleran area continued to exist without a break from the Lower Cambrian, but it now spread over the interior of the continent south of the international boundary, and as far east as the land-areas known as 'Appalachia' and 'Acadia,' bringing with it the Asiatic type of fauna. But east of these land-masses there were distinct Atlantic faunas, comprising the *Protolenus* fauna of New Brunswick at the base of the series, and the *Paradoxides* fauna above, and extending from Newfoundland to Vermont. In the Pacific province *Olenoides* and the big-tailed trilobites *Ogygopsis* and *Bathyriscus* are, on the other hand, characteristic of the homotaxial deposits.

The Upper Cambrian period was marked by a great invasion of the centre of North America by the Gulf sea from the south, distributing its fauna far to the north into the St. Lawrence trough, but apparently not passing out into the Atlantic. The faunas of New Brunswick and Newfoundland^{287 377} thus became wholly different from those of the rest of the continent, and are in harmony with those which lived in Europe⁵²⁷ at the same time, containing *Olenus*, *Parabolina*, *Peltura*, etc. It seems that they flourished in small gulfs with short direct communication with the Atlantic. The characteristic trilobite of the Upper Cambrian Gulf fauna is *Dicellosephalus*⁸² which is abundant in the Potsdam Sandstone, and at this period there is the first distinct molluscan fauna.

The Pacific sea seems to have been shut off at this stage, and no *Paradoxides* or *Olenus* fauna is known from it.

Ordovician^{149 241 389}

The Ordovician of North America occurs under so many different types, and is of so variable a character that the exact correlation of the beds is a

matter of uncertainty. But the graptolite zones, which are found in some parts¹⁴⁹, are capable of being correlated with those of Great Britain and Scandinavia¹⁵², and furnish us with a firm foundation for comparison. The faunas of the Ordovician beds, especially those in Ontario, Quebec, and Manitoba on the Canadian Shield, have been described by Cooper²⁶¹, Raymond⁵⁹⁸, Foerste¹⁹³, Parks³⁵¹, Wilson²⁷⁵, and many others, and in Anticosti Island especially by Twenhofel²⁵³.

(1) ACADIAN REGION.—The Lower Ordovician here succeeds the Upper Cambrian without a break, and forms part of Matthew's 'Bretonian' division, which is developed in **Cape Breton** Island and St. John's, **New Brunswick**¹⁴ 33a 290 398. It consists of black carbonaceous shales containing a rich graptolite fauna, including *Tetragraptus* and *Didymograptus*³⁹⁸. In the Bathurst district graptolitic shales are found equivalent in age to the Lower Trenton¹¹². There is a remarkable affinity with the Lower Ordovician faunas of Great Britain, and many of the species of graptolites are identical. From Alabama to southern Virginia the same faunas are found possessing this Atlantic facies.

In **Nova Scotia** there is in the Arisaig-Antigonish district^{26 121} a series of red slates and greywackes with three beds of oolitic iron ore containing linguroids like those in the famous iron-ore deposits of Newfoundland, but the beds are highly metamorphosed, and are intruded by granites, diabases, and other igneous rocks.

In **Newfoundland**⁵⁴⁴ the most important Ordovician beds are those on Bell Island, Conception Bay²⁶³, where the beds form part of the northern limb of a great anticline. The fossiliferous shales and sandstones are intercalated with valuable beds of oolitic iron-ore, chiefly hæmatite, containing fossils (*Didymograptus*, etc.), which indicate a Lower Ordovician age, and correspond with those of New Brunswick^{290 398}. The Wabana Iron Mines^{263 536} on Bell Island are the most important mineral deposit in Newfoundland. The Cambrian and Ordovician rocks lie here in a gentle synclinal basin traversed by many faults. In the Upper Ordovician in the Trout River area there are interbedded intrusive sheets or laccolites of peridotite. The ore-beds seem to have been primary sediments^{69 263}.

The widest development of the Ordovician^{149 289 531} is in western and northern parts of the island, as in Canada Bay⁵³¹, where Lower and Middle beds are present and have been classified into series with local names²⁸⁹. The basal series of the Lower Ordovician consists chiefly of greenish shales with graptolites, and of layers of conglomerate, and is termed the *Green Point Series*. It is followed by the *St. George Series* of dolomites, limestones, and pink sandstones, which contain fossils (brachiopods, mollusca, and trilobites). Both these series are referred to the Canadian. The Middle Ordovician beds, which are represented by the *Table Head* and *Long Point Series* of limestones and shales, are correlated respectively with the Chazyan¹⁴⁹ and Black River formations; the former contains many typical fossils, especially cephalopods and trilobites. The *Long Point Series* is rich in brachiopod species, and amongst its beds is the peculiar 'Cow Head Breccia,' containing blocks of Lower, Middle, and Upper Cambrian, as well as of Lower Ordovician limestone, in angular fragments. In Notre Dame Bay²⁸⁹ the Lower and Middle Ordovician are represented by graptolitic black shales, containing many genera and species of graptolites. Andesitic and rhyolitic lavas and tuffs are here found associated with the Ordovician beds. The Lower and Middle Ordovician fossils from Newfoundland were first described by Billings, but many of the brachiopods and trilobites by later palaeontologists.

On **Akpatok Island** in Ungava Bay, Labrador, an abundant Richmondian

fauna has been found^{896 524} like that in north-west Greenland. On Southamp-ton Island, at the mouth of Hudson Bay, nearly horizontal beds of Ordovician or Silurian limestone form terraced plateaus⁶⁰⁵.

In the neighbourhood of **Quebec**¹⁸ the Ordovician beds are involved in complicated folding and faulting, so that the beds of two faunal facies and basins of deposition are brought into juxtaposition. Three major strike-faults, two of them thrust-faults, run from north-east to south-west. The oldest beds, chiefly exposed in the south of the St. Lawrence, belong to the *Sillery Formation*¹⁴⁹ (partly referred to the Cambrian), which consists of red and green shales with lenticular masses of red and green sandstone. Fossils are almost entirely lacking, but the presence of *Linarssonina pretiosa* with *Phyllograptus* and other graptolites points to the Lower Ordovician age of part of it. Limestone-conglomerates occur also in beds the pebbles of which contain Lower Cambrian and occasionally Upper Cambrian fossils. Next in order comes the *Levis Formation*, consisting of shales, thin-bedded limestones, and limestone-conglomerates, which contain pebbles with Lower Cambrian, Upper Cambrian, Sillery, and Beekmantown⁵¹⁸ fossils. Over 1000 ft. of strata are exposed near Levis. These peculiar conglomerates occurring in connection with the Sillery, Levis, and Quebec City Formations in the Quebec area are believed by some geologists⁴⁸⁰ to be due to submarine landslips in the earlier stages of the development of a geosyncline. The shales yield a graptolite fauna, principally belonging to the genera *Phyllograptus* and *Tetragraptus*, while the limestones contain *Shumardia* and graptolites. The Levis beds are thrust over the stratigraphically higher *Quebec City Formation* which consists of limestone, very dark shale and thin limestone-conglomerate. The shales yield graptolites (*Climacograptus bicornis*, *Cryptograptus tricornis*, *Corynoides calicularis*, etc.), indicating a Middle Trenton age, and the pebbles contain Lower Trenton and Black River fossils. The Quebec City Formation is thrust over Utica-Lorraine beds like those of the Lowland district (see below), and true Trenton Limestone rests directly on the Pre-Cambrian rocks around the Montmorency Falls. In the Chaleur Bay area³⁸⁶ the Middle Ordovician is represented by graptolitic shales associated with interbedded flows of andesitic and basaltic lavas. A complex of beds consisting of limestones, argillites, and quartzites in the Matapedia valley of this area has yielded a few Upper Ordovician trilobites and brachiopods³³⁶. In the *Perce Area*, *Quebec*, the Ordovician rocks are chiefly represented by the Upper beds containing an abundant fauna of brachiopods, cephalopods, and trilobites^{261 347 348 636}. But the Sillery and Levis beds also are present in the Gaspé peninsula²⁸¹, where great masses of serpentine and amphibolites invade the Ordovician volcanic complex, but do not intrude the Silurian or Devonian rocks^{233 281}. In the Chaudière basin in south-eastern Quebec the Ordovician is supposed to be represented by the *Beauceville Series*²¹⁹, which consists of extrusive igneous and sedimentary rocks, including acid tuffs, rhyolite flows, slates, quartzites, and conglomerates, all much folded and faulted (Fig. 14, p. 369).

All the Cambro-Ordovician beds in the Acadian region are highly disturbed, folded and faulted, having been deeply affected by the movements of the *Taconic* epoch of orogeny in late Ordovician times. The belt of deformation stretched from Newfoundland as far south-westward perhaps as Virginia, and was wide enough to include most of New Brunswick, and perhaps Nova Scotia. Representatives of most of the Ordovician horizons which are found in the Lowlands (see below) have been recognised in this Acadian area, but with a different facies, and most of them are graptolitic shales¹⁴⁹. The geological structure of this whole region is extremely complicated owing to the amount of disturbance which these older Palaeozoic rocks have suffered and to the intrusion of granite batholiths.

(2) **CANADIAN SHIELD**.—Outliers of Ordovician beds of greater or less extent occur on the Canadian Shield on both sides of Hudson Bay, and also between James Bay and Lake Huron, and show that there was a partial marine transgression here over the Canadian Shield. The beds are mostly horizontal, and exhibit the same general development and characters as those of the Lowlands of the St. Lawrence (see below). The *Black River Limestone*, containing *Maclurea*, etc., occurs on Lakes Timiskaming^{194 537} and Nipissing, and the *Trenton Formation*, which is widely spread, has yielded many fossils. The *Utica* and *Richmond Formations* are also represented as outliers on the ancient gneiss in the Lake St. John district, Quebec¹³³. Far to the north in Baffin Land³⁷⁰ and in the Arctic Islands, outliers of Ordovician beds are also known^{172 256 368 535 536}.

(3) **LOWLANDS OF THE ST. LAWRENCE**^{149 153 527}.—It is in this region that the best and fullest series of Ordovician rocks has been studied, for they are widely developed in the great expanse of flat land bordering the St. Lawrence and Ottawa Rivers for 200 miles above and below the mouth of the Ottawa, including parts of Quebec and Ontario.

In the neighbourhood of Montreal and Ottawa¹⁹ the following succession is found:—

Upper	{	Richmond Formation.
		Lorraine ,,
		Utica ,,
Middle	{	Trenton ,,
		Black River (including Lowville) Formation.
Lower	{	Chazy Formation.
		Beekmantown Formation (=Calciferosus Formation).

The **Beekmantown** (or Calciferous) overlies the Potsdam bandstone, and consists chiefly of limestone and dolomite, often arenaceous, containing such typical fossils as *Ophileta complanata*, *Pleurotomaria canadensis* and species of *Bathyurus*, *Holasaphus*, *Isoteloides*, etc.⁵¹⁸. It is about 250 ft. thick at Montreal, but in the Province of Quebec reaches a thickness of 450 ft.

The **Chazy** is chiefly represented by sandstones and shales with some limestones. It is not usually important in Ontario²⁷⁵. *Camarotoecchia plena*, *Sigmacystis*, and *Maclurea magna* are characteristic fossils. It is 200-300 ft. thick near Montreal.

The **Black River Group**⁶⁵⁰ is divided into several portions. For the most part, it consists of limestones and in parts contains masses of black chert. Species of *Bathyurus* are common, and *Tetradium fibratum*, *Columnaria halli*, *Hormoceras*, *Goniceras* may also be mentioned amongst the fossils^{275 407}. As developed in Ontario, it varies in thickness from 150 to 200 ft.

The **Trenton** is divisible into several horizons, and varies in character. It is mainly composed of calcareous beds, generally of a bituminous nature. *Trinucleus concentricus*, *Parastrophia hemiplicata*, *Dalmanella*, *Tetradium*, *Prasopora*, and cystideans mark different beds^{261 275 402 407 475}. The Trenton is supposed to be about 600 ft. thick in the provinces of Quebec and Ontario, and in places rests directly on the granite and gneiss. It is one of the most important formations in Ontario in connection with the occurrence of oil and

The **Utica Group** consists of a lower group (*Collingwood Group*), 25-50 ft. thick, which is found at Ottawa and in southern Ontario⁴²⁴, and is composed of **alternate beds** of limestone and shale. *Ogygites canadensis* is the commonest

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fossil. The upper part of the Utica (*Eden Group*) consists of 200-300 ft. of black shales, with a fauna chiefly of graptolites (*Climacograptus*, *Diplograptus*, etc.), and they contain also the trilobite *Triarthrus becki*⁹⁵.

The Lorraine Group consists chiefly of sandstone and shale in thin layers, with numerous thin calcareous bands. *Catazyga erratica*, *Pterinea demissa*, *Cyrtolites ornatus*, and *Isotelus maximus* are common and characteristic fossils^{193 395}; lamellibranchs are also abundant. In the province of Quebec the Lorraine has a thickness of about 2000 ft., but in Ontario averages only 300 ft.

The Richmond Group consists of sandstones and shales with a large fauna^{193 26135}, the commonest form being *Catazyga headi*, while *Hebertella insculpta* is also characteristic. The beds are well developed on Manitoulin Island in western Ontario, and are exposed at many places between Georgian Bay and Lake Ontario, and also on Lake St. John about 120 miles north-west of Quebec.

The Lorraine of New York, and the Lorraine of Quebec and of the extreme eastern portion of Ontario seem to represent sedimentation in different basins with resulting differences in the fossil contents. In western Ontario there is likewise a local development³⁵¹ with distinctive palaeontological features. In the Toronto area^{351 424} the Ordovician has rather a peculiar development, but the beds are partly correlated with the Utica, Lorraine, and Richmond Groups, the whole formation being termed the Dundas Formation. The beds have an abundant fauna, and lamellibranchs are particularly common and characteristic.

The upper part of the Richmond Formation is separated off by some authors as the *Queenston Formation*. It consists typically of red shales containing abundant ostracods (*Drepanella*, *Eurychilina*, etc.)¹⁹³, and is represented on the shores of Lake Ontario and in eastern Ontario and Quebec. North-east of Montreal the formation has a thickness of 1000 ft. or more, as in New York.

The Ordovician beds are horizontal, or nearly so, over the whole area, except in the immediate vicinity of faults (which are nearly all normal ones), and occur on the south side of the great Laurentian escarpment. All the formations appear to succeed one another conformably. It is probable that they extended formerly far over the Laurentian Shield, for the escarpment of the latter owes its origin to later faulting and to differential erosion. There is a belt of Pre-Cambrian rocks extending from the Lake Nipissing district to the head of the St. Lawrence, and separating off the Palaeozoic lowland which borders the Ottawa and St. Lawrence Rivers from the Palaeozoic area of the Ontario Peninsula, where the beds have a very gentle dip to the south-west.

In **Anticosti Island**^{20 21 263} there seems to be a complete passage between the Ordovician and Silurian, and the beds have thus needed a special classification. The dependence of faunas on the lithological characters of the beds is strikingly demonstrated in the great differences of the fossils in the deposits on the north and south shores of this island. The Richmond and overlying 'Gramachian' series of beds have a thickness on this island of over 1300 ft.

In the **Mingan Islands**^{248 291} the Ordovician beds, which are only slightly tilted and form the unsubmerged summits of two *cuestas*, contain typical fossils of the Chazy limestone.

(4) INTERIOR CONTINENTAL PLAIN.—In **Manitoba** the Ordovician rocks are rather extensively developed, forming the main band of Palaeozoic rocks which extends along the west side of Lake Winnipeg^{154 256} and from its northern end far to the west across Saskatchewan to long. 108°. The beds are

almost horizontal and undisturbed, and rest directly on the Pre-Cambrian, showing the existence of a land area in pre-Ordovician times, and a long early Palaeozoic period of erosion^{125 171}. The equivalents of the Black River, Trenton, Lorraine, and Richmond formations of eastern Canada have been recognised. The lowest beds are sandstones, and these are overlain by limestones (largely dolomitic) and shales. It has been pointed out^{256 567 558} that the wide distribution of the Ordovician cephalopod fauna in northern regions, such as in southern Manitoba, may be regarded as indicating a special boreal fauna composed chiefly of Canadian and American Arctic forms. The *Stony Mountain Formation*⁶⁰⁹ of Richmond age on the west shore and islands of Lake Winnipeg contains such a fauna, and the underlying *Red River Formation* has similar affinities; though the corals of the latter are more like Silurian species, Whiteaves⁴⁰⁷ placed it in the Trenton. Beneath it the *Winnipeg Sandstone* may be of Black River age. In the Amisk^{171 366} Lake district, on the boundary between the provinces of Manitoba⁴⁰⁷ and Saskatchewan, the Ordovician is represented almost wholly by dolomites, 86-112 ft. in thickness, and almost horizontal. The Ordovician rocks of the North Arm, Great Slave Lake^{532 352a 376}, have yielded fossils (*Receptaculites*, *Endoceras*, etc.). The beds consist of limestones and shales and belong to the Lower Ordovician. It is probable that Ordovician rocks underlie the whole of the Silurian, Devonian, and Cretaceous beds of the eastern prairies. The faunas of these beds on the western fringe of the Canadian Shield have been described by Whiteaves⁴⁰⁷, Parks, and others.

(5) ARCTIC ARCHIPELAGO^{155 162163169 172 256 368 376 536 557}.—The Richmond, Trenton, and Utica formations are represented in several parts of north-eastern Arctic America, and show the typical characters and fossils, as in Baffinland^{370 535 536}, while the Cambro-Ordovician beds have a similar development in Ellesmereland^{559 560 812 644}.

(6) CORDILLERAN REGION.—Ordovician formations, chiefly limestones and shales, occur at wide intervals along the course of the Rocky Mountains in the eastern geosynclinal as far north as the Mackenzie River^{241 349 389 498 511}. In British Columbia, near Banff and Hector, on the C.P.R.^{51 99}, Ordovician rocks, approximately 8000 ft. thick, lie conformably on the Upper Cambrian. The base of the Ordovician in the Rockies is formed by Walcott's *Mons Formation*³⁸⁹, according to Raymond⁴⁹⁸; it consists of calcareous shales with interbedded limestones. The *Goodsir Formation*^{241 389} constitutes the rest of the lower division, and is estimated to be over 6000 ft. thick, consisting of argillaceous and calcareous slates, cherts, and impure limestones alternating in thin bands, and containing *Ceratopyge* and other fossils. This formation, which contains a transitional fauna^{607 617}, was at first put by Walcott^{349 389} in the Upper Cambrian. It contains the *Housia* fauna, and is typically developed in the Othertail Mountains, and is overlain by massive limestones known as the *Othertail Formation*. A graptolitic facies is found elsewhere in the Rockies, as, for instance, in the Kicking Horse Canyon, near Glenogle in the Beaverfoot Range, and in the Windermere area²³², and farther south in the Brisco-Stanford Range^{349 389}, where there is a thick series of shales and sandstones (the *Glenogle Shales*) measuring over 2000 ft. thick and containing a large series of graptolites²³² (*Didymograptus*, *Phyllograptus*, *Tetragraptus*, etc.) corresponding to part of the Beekmantown Formation (Lower Ordovician) of New York. On Skoli Mountain, near Lake Louise, siliceous and magnesian limestones have yielded a fauna of Chazyan character. According to Walcott^{349 389}, Burling²²⁴, and Wilson²³⁹ the *Beaverfoot Formation* in the Beaverfoot-Brisco Range in the southern Rockies, chiefly consisting of limestone and previously termed the Halysites beds^{99 232} (which were referred

by Walcott³⁸⁹ to the Silurian (see below)), should be correlated with the Richmond (Upper Ordovician) on the evidence of recent fossil collections. The beds, which consist of dolomite, limestone, white quartzite, etc., have a thickness of over 1800 ft., and succeed the Glenogle Shales conformably. The Richmond (Beaverfoot) beds are transitional into the Silurian (Brisco) beds of the Windermere map area^{232 349}, and no divisional line can be here drawn between the two. Wilson²³⁹ has described species of *Streptelasma*, *Dinorthis*, *Rhynchotrema*, *Syringopora*, etc., as well as of *Halysites* from these Ordovician beds. In the Mount Kobson district^{78 38 9 607} the Robson Limestones, 500 ft. thick, succeed the *Chushina Formation*, which contains a fauna of brachiopods (*Lingulella*, *Acrotreta*, *Eoorthis*, etc.) and trilobites (*Symphymrina*, *Hystriacus*, *Xenostegium*, *Kainella*, etc.) indicating an Ozarkian (Tremadoc) age⁸⁸⁹. The beds of this formation consist of thin-bedded limestones with interbedded shales, and are estimated to measure 1500 ft. in thickness, resting on the Upper Cambrian. The fullest details of these sections in the Rockies are given by Walcott³⁸⁹. The Ozarkian fauna is also found in the Palisade section²⁹⁹ on the Athabasca River, where thin-bedded limestones in the *Sarceen Series* contain small brachiopods and trilobites. The Ordovician is also found in other parts of Jasper Park; the succession and the fossil contents of the beds are given by Kindle²⁹⁹ and Raymond⁴²⁶.

Graptolitic shales also are found on the Dease River in Yukon territory, lat. 60°, long. 130° W.; there is in the Porcupine River district on the Yukon-Alaska boundary^{96 374} an important series of limestones and dolomites, which contain Ordovician and Silurian fossils, and seem to represent both systems.

GENERAL REMARKS ON THE ORDOVICIAN.—The Ordovician period as a whole was marked by many marine inundations and emergences, and possessed a multitude of faunas, local and provincial in character.

A curious feature in the Appalachian region is the existence of long narrow troughs separated by long narrow barriers on either side of which the formations are both physically and faunistically distinct, though synchronously deposited. It is probable that subsequent to their deposition there has been much foreshortening of the entire Appalachian and Piedmont region by north-westerly thrusting, and that the dividing ridges were originally much wider, and have subsequently assumed forms unlike those which they originally possessed. In Lower Ordovician times the Levis trough was completely separated from the sea to the west, in which the Beekmantown was deposited. In Middle Ordovician times, the greatest submergence during the whole Ordovician took place in the Trenton stage¹⁷, but even then the Appalachian-Acadian land-barriers were effective in preventing the intermingling of the Pacific and Atlantic faunas, the latter of which were represented by graptolitic beds with European species. The main invasion of the rest of North America took place from the north, so that the life of the Pacific mingled with that of the Arctic region. In the Upper Ordovician, after a retreat of the sea, there was a fresh submergence, and in Anticosti Island we have evidence that continuous deposition went on into Silurian times. A summary of the general palæontological character of the North American Ordovician and affinities to the Eurasian is given by Troedsson⁶²⁹.

Silurian

(1) ACADIAN REGION.—Towards the close of the Ordovician the whole Appalachian region of eastern America was involved in a series of mountain-building movements (the Taconic), and much (if not all) of the eastern portion of the Continent was elevated above the sea, so that the strata were not only

folded but eroded before the land again subsided beneath the Silurian Sea, which spread in its turn over much of this region. The Silurian is extensively developed in Nova Scotia^{151 211}, Quebec^{233 281}, and New Brunswick^{149 336} as long narrow bands trending north-east to south-west, and is widely distributed in Newfoundland²⁸⁶, forming the most fertile belts of land and forest areas.

At Arisaig^{261 211 512 111} in **Nova Scotia**, there are five distinct formations in the *Arisaig Series*, with a total thickness of about 3800 ft., resting with an unconformity on the Ordovician. The fauna is more European than American in character, yet unlike that of either country. The lowest stage (the *Beech Hill Cove Formation*) consists of fine-grained greenish calcareous sandstones, etc., with many corals and brachiopods. Above come black and green shales and impure limestones (the *Ross Brook Series*) with brachiopods, lamelli-branches and many zones of graptolites (*Monograptus*). Both of these formations are correlated with the Valentian. Resting on the Ross Brook beds are the *McAdam and Moydart series* of heavy-bedded light greenish-grey calcareous strata and a brick-red shale, containing a varied fauna of brachiopods, gastropods, cephalopods, crinoids, etc., of Salopian age. The uppermost division is the *Stonehouse Series*, which is most fossiliferous, and consists of dark-red fine-grained shales and mudstones with a conspicuous lamellibranch fauna (*e.g.* *Grammysia acadica* Billings) and calcareous bands with brachiopods (*Chonetes novascoticus*, *Dalmanella lunata*), trilobites (*Homalonotus*), Merostomata (*Pterygotus*), etc., the whole facies closely corresponding with the Ludlow of the British Isles²¹¹. A characteristic feature of the fauna of the whole succession is the rich development of certain bivalve families¹⁵¹ and the affinity of many species with British forms²¹¹.

In the vicinity of the Bay of Fundy coralline limestones and graptolitic shales of Silurian age are extensively developed, but are much cleaved, crushed, and metamorphosed, and in the eastern townships of **Quebec**³³⁶, south-east of the great fault, the beds are likewise in places much altered, frequently into mica-schists. In the Mount Albert area²³³ there are shales, crinoidal limestones, and quartzites, containing typical Silurian fossils. In the Chaleur Bay area³³⁶ there are two main groups of Silurian rocks, one in the vicinity of Chaleur Bay, as at Port Daniel and Black Cape⁶⁵³ on the Gaspé coast, and known as the *Chaleur Series*, and the other in the Matapédia³³⁶ Valley which has a rather different development. The largest area of Silurian rocks is in the Port Daniel-Black Cape region on the north side of Chaleur Bay where Northrop⁶⁵³ divides the Chaleur Series into seven formations having a total thickness of about 6500 ft. The whole series is referred to the Middle Silurian, and consists of a varied succession of shales, limestones, sandstones, and occasional conglomerates containing a rich fauna of brachiopods, trilobites, mollusca, corals, cephalopods, etc.⁶⁵⁵ with a definite North European impress like those in the Acadian trough⁶⁵³. In the Black Cape section there are interbedded flows of basaltic lava, one of which reaches a thickness of over 3600 ft.

The western and north-western parts of **New Brunswick** possess well-developed Silurian beds like those of the Lowlands of the St. Lawrence, and the Lower Helderberg, Guelph, and Niagara formations have been recognised, but they are usually highly folded and faulted, and are associated with many varieties of igneous rocks, some contemporaneous.

In north-eastern **Newfoundland** conglomerates and sandstones, slates and calcareous flags, often metamorphosed, are referred to the Silurian, and some of the most widely developed beds have yielded fossils indicating Llandovery

(Clinton and Medina) horizons^{249 286 289 308 653}. A rich fauna from the Silurian rocks of Notre Dame Bay has been described by Twenhofel and Shrock²⁸⁶, indicating the presence of beds of a Clinton (Middle and Upper Llandovery) age. The series, which consists of sandstones, conglomerates, and argillites, are folded and invaded by post-Clinton sills and dykes. Another group of exposures of Silurian fossiliferous sandstones of the same age have been described in White Bay on the north-east coast⁵⁷⁰, containing corals (*Favosites*, *Clathrodictyon*, *Heliolites*).

According to Ellis¹³⁷, the formation of the great Champlain-St. Lawrence fault took place at the same time as this folding of the Silurian, and about the date of the deposition elsewhere of the Lower Helderberg beds. The whole history of the Gulf of the St. Lawrence^{252 280} seems to begin with this event.

(2) LOWLANDS OF THE ST. LAWRENCE.—In Anticosti Island^{157 253} the lowest Silurian is scarcely separable from the Ordovician, a continuous series passing up into the equivalents of the Medina Formation of New York²¹ and containing considerable faunas²⁵³ of a Llandovery stamp. Four distinct formations, chiefly of limestones with some shales, have been recognised in the series.

Along the south side of the St. Lawrence, the lowest Silurian or 'Medina Formation' is represented, but the upper beds have been removed by subsequent erosion.

In **Ontario** the Silurian formations are continuous with those of New York, and are but slightly disturbed, but they vary in development and character with the distance from the sources of the clastic material. Thus at Credit Forks, about 70 miles north-west of Niagara Falls, the Clinton and Rochester deposits are absent, and the upper sandy portion of the Medina has disappeared. In south-western Ontario the full sequence of beds is as follows¹³²:—

5. Cayugan Group (including the Salina Formation).
4. Guelph Group.
3. Niagara Group.
2. Clinton Group.
1. Medina-Cataract Group.

The *Medina-Cataract Group*, which corresponds with the Lower Llandovery, rests without an unconformity on the Richmond beds (= Queenston shale), at Cataract junction, near Toronto, and consists of sandstones, shales, dolomites, and limestones. The beds change much in character and thickness when traced laterally, the basal bed on the Niagara River being sandstone. Each petrological type and horizon has its peculiar faunal assemblage.

In eastern New York the *Medina Group* is represented entirely by sandstones and conglomerate. Brachiopods, including some European species, mollusca, and corals are abundant in the more calcareous and argillaceous deposits.

The *Clinton Group* in Ontario consists of less than 50 ft. of shales and magnesian limestones, and contains *Pentamerus oblongus* (Sow.), *Hyattidina congesta* (Conr.), *Iuænus barriensis*, etc. Only the upper part of the Clinton of New York is present in Ontario. It is correlated with the Upper Llandovery and Tarannon of Wales and Shropshire.

The *Niagara Group*, of Wenlock age, has a maximum thickness of about 200 ft. in the Niagara district, and consists chiefly of limestones, with dolomites, abounding in fossils, especially corals and brachiopods. The upper part of the group forms the Niagara escarpment, and the calcareous members thicken to the north-west. At its base is the Rochester Shale; the upper part is known as the *Lockport dolomite*^{459 468}, which is the most important member,

and outcrops nearly all the way from Niagara Falls to Cockburn Island on Lake Huron¹³². The former is confined in its outcrop to the Niagara Peninsula in Ontario, and is rich in brachiopods, bryozoa, and trilobites. It is the Lockport dolomite⁴⁵⁹ which forms the top of the cliff over which the Niagara River falls^{428-431 468}. The base of the cliff and three parts of its height are composed of the Rochester Shales and Clinton beds, and it is owing to the softer nature of the Shales that the face of the cliff has been undercut and has receded in consequence of the gentle southward dip of the strata. The fullest description of the Falls has been given by Spencer⁴⁶⁸ and Grabau⁴²⁸, but more recently the rate and character of the recession of the Falls and their relation to the Upper Gorge have been dealt with by Boyd^{429 431} and Johnston⁴³⁰.

The *Guelph* and succeeding Silurian formations spread over a considerable portion of the Ontario Peninsula⁴⁶¹, east of the Devonian outcrop, having wide surface exposures. The *Guelph* consists largely of cream-coloured dolomites, highly fossiliferous. Near Niagara Falls its thickness is about 140 ft. *Megalomus canadensis* is a characteristic fossil, and species of the peculiar brachiopods *Trimerella* and *Monomorella* are typical, while there are also many species of gastropods and cephalopods.

The term *Cayugan Group* is used by Williams to include all the Silurian sediments above the top of the *Guelph* dolomite. Of these the *Salina Formation* averages 1000 ft. thick in Ontario⁷², but is only 300 ft. thick at Niagara Falls, and is composed of beds of gypsum, salt, dolomite, and shales, representing special conditions of sedimentation, probably those of an interior basin. The salt beds are sometimes as much as 400 ft. thick. Some of the muddy calcareous sediments contain a rich eurypterid fauna⁶⁷⁰.

The lower part of the *Monroe Formation*, which is composed of dolomites, limestones, etc., has a very restricted development at the extreme west of the Ontario Peninsula, and is now called the Bass Island Series, as in Ohio and Michigan.

The Upper *Monroe* beds are now referred to the Devonian. The whole *Cayugan Group* is correlated with the Ludlow beds of the British Isles.

(3) CANADIAN SHIELD.—Silurian beds of Niagaran age, highly fossiliferous, are found resting with a great unconformity on the Pre-Cambrian near Cobalt, and on the Nelson River on the west side of Hudson Bay. On Southampton Island⁶⁰⁵, in the same bay, the Silurian is said to follow the Ordovician in unbroken succession; in the Lake Timiskaming area⁵³⁷ the Lockport dolomites are represented and contain many fossils.

(4) INTERIOR CONTINENTAL PLAIN.—The Silurian is extensively developed between Lakes Winnipeg and Winnipegosis⁶¹⁵, and consists of flat-lying limestones, dolomites, and shales, referable partly to the *Guelph* and partly to the Niagaran formations. Corals, brachiopods, etc., occur in considerable abundance at the various exposures in Manitoba⁴⁰⁵. The whole formation, which has a thickness of about 200 ft., largely consists of dolomites. It extends westward into Saskatchewan, past Cumberland Lake. Silurian as well as Ordovician fossiliferous rocks occur on Great Slave Lake^{352 352 a 376}.

(4a) ARCTIC ARCHIPELAGO.—The southern islands of the Arctic Archipelago are extensively covered by Silurian strata related to those around Lake Winnipeg^{158 162 163 368}. The Niagaran⁶⁴⁴ formation is the most widespread. In Ellesmereland there is a complete succession from Ordovician to Upper Devonian^{149 559 560 644}. A general survey of the Silurian of the Arctic has been given by Foerste²⁵⁶.

(5) CORDILLERAN REGION.—Not much is known at present about the general development of the Silurian in this region. A number of limited areas have yielded Silurian fossils. Along the Columbia River in the Sinclair Canyon Section³⁴⁹ the Silurian is represented by thick-bedded limestones about 1200 ft. thick, containing corals³⁸⁹, etc., with black shales intercalated, containing a Clinton graptolite faunule (*Monograptus marri*, *M. cf. spiralis*, *Retiolites geinitzianus*). These beds are sometimes termed the *Brisco Formation*^{349 389}, and occur in the Brisco Range. The *Halysites* beds^{232 889} of the Beaverfoot Range, which are now (as above mentioned) regarded as Upper Ordovician, were formerly⁹⁹ put in the Silurian. In the Yukon-Alaska boundary district, fossiliferous Silurian beds are also developed⁹⁶.

GENERAL REMARKS ON THE SILURIAN.—According to Schuchert¹⁷, the American Silurian deposits are geographically divisible into three provinces on the basis of their faunas, chiefly by means of the crinoids and brachiopods : (1) the *Atlantic* province, including the St. Lawrence, Appalachian, and Indiana sub-provinces ; (2) the *Hudson* province, with faunas of Arctic and North European derivation ; and (3) the *Cordilleran* province, which is evidently Pacific in its faunal characters, but is at present comparatively little known. Walcott^{241 389} has pointed out that in pre-Devonian times the Cordilleran geosyncline had its bottom wrinkled so as to form several more or less independent troughs in which the deposition and succession of strata was somewhat different. Several troughs in Palaeozoic time are recognised by him—the Bow trough on the eastern side of the geosyncline, which had connection with the Glacier Lake trough to the north. The Goodsir trough follows to the west, and then the Beaverfoot trough. Owing to the faulting and eastward thrusting of the sedimentary formation the boundaries of the troughs are often obscured. The Sawback trough, which is superjacent on the Bow trough, had a set of sediments deposited in it which are not found elsewhere in the Bow trough. The Robson trough contains formations of the general character of those of the Glacier Lake and Bow troughs, but differ in details and in faunas. The known Palaeozoic deposits in this trough have a thickness of 13,300 ft. All these subsidiary troughs have a general north-and-south trend. The prevailing rock in the pre-Devonian Palaeozoic formations in the Cordilleran area is calcareous ; of a total thickness of 28,000 ft. from the Pre-Cambrian to the top of the Silurian in the combined Bow, Goodsir, and Beaverfoot troughs over 16,000 ft. consist of limestones of varying character and purity⁸⁶⁸.

Devonian

(1) ACADIAN REGION.—Devonian strata are widely distributed over this region. The earlier beds are often largely calcareous, and their fossils indicate true marine conditions ; but considerable portions consist of shales and sandstones, rich in the remains of land-plants, and laid down in lakes or estuaries.

True marine calcareous beds are present at a few points in south-eastern **Quebec**. The Lower and Middle Devonian are well represented in the Chaleur Bay region³³⁶, the *Dalhousie Formation* (New Brunswick) being of Helderberg age and containing an abundant marine fauna²⁹. Associated with the sedimentaries are flows of andesitic and dacitic lavas. Intrusive dykes of acidic, intermediate, and basic types, as well as granite stocks, invade them. The volcanic rocks, termed the *Restigouche Volcanic Series*, which have been described by Howard⁴⁰¹, are unlike those in the neighbouring petrographical province. The *Dalhousie Formation* extends across the border from Quebec into New Brunswick with the same characters, while at the extremity of the Gaspé Peninsula^{29 30 281} these marine deposits are represented by about 2000 ft. of

shales and calcareous beds overlain by conglomerates, sandstones, and shales with plant-remains and thin coals. The beds are over-folded and over-thrust upon the Ordovician-Cambrian rocks. The Lower Devonian limestones (*Gaspe Limestone*²⁹) contain marine fossils of the Helderberg and Oriskany formations, and there is a gradual passage upwards from the Niagara till the appearance of the Oriskany fauna. The overlying '*Gaspe Sandstone*'²⁹ contains Middle Devonian (Hamilton) marine fossils in its lower parts, and generally an abundance of terrestrial plants. Its thickness is believed to be over 7000 ft. Amongst the plant-remains in the *Gaspe Sandstone* the chief fossil is *Psilophyton*. This sandstone covers wide areas in the interior of Gaspe, and in the Mount Albert area²³³ it rests on a thick series of volcanic rocks. A considerable fish fauna, including species of *Cephalaspis*, *Climatius*, *Cheiracanthus*, etc., has been found in the Restigouche area. The line drawn here between the Middle and Upper Devonian is somewhat arbitrary³³⁶; the Upper beds consist of shales, conglomerates, and sandstones which contain fossil fish (*Bothriolepis*, etc.)³⁸⁶ and plant-remains⁴⁵⁴ (*Archæopteris*, etc.) in the uppermost or *Scaumenac Formation*. The conglomerates (*Fleurant Formation*) at Scaumenac contain striated pebbles which are ascribed to glacial action. Thick red conglomerates and sandstones, known as the *Bonaventure Formation*, which cover the *Gaspe Sandstone*, seem to be partly late Devonian and partly early Carboniferous in age³⁸⁶. As the latter they are frequently grouped in Cape Breton Island, where they occur directly below the Mississippian limestone and shale series.

In the eastern provinces there is a marked change in the conditions of sedimentation about the time of the appearance of the Oriskany fauna, as in the case of the transition from Silurian to Old Red Sandstone in Wales.

In the Beauceville map area in the Chaudiere Basin²¹⁹ the Devonian is represented by a series of shales, slates, conglomerates, and fossiliferous limestones at St. George⁶²⁶, with many corals, probably of Onondaga age (Middle Devonian); these beds rest with an angular unconformity upon Ordovician beds.

In Nova Scotia and New Brunswick^{115 121 290}, the so-called *Knoydart Formation*¹²⁷ of red shales, sandstones, and calcareous bands apparently overlies the Silurian (Arisaig Series) unconformably, and a volcanic ash-bed in the series contains pteraspidian and ostracoderm fish (*Cephalaspis*, *Pteraspis*) and eurypterids (*Pterygotus*). It resembles the Cornstones or Lower Old Red Sandstone of Great Britain¹²⁷.

In the southern part of New Brunswick^{72 115}, the so-called Devonian has a considerable development, and consists of five groups of sandstones, shales, and conglomerates with abundant plant-remains; two of these groups are characterised respectively by the presence of *Dadoxylon* and *Cordaites*. Some of these beds seem to be an extension of the Perry Group of Maine of Upper Devonian age, but it is probable that others are of Middle or Upper Carboniferous age¹⁴⁹. Near St. John's, New Brunswick, a coarse conglomerate, containing boulders up to 3 ft. in diameter, reaches a thickness of 240 ft. and extends over a large area. It is said to resemble a moraine and may be due to ice action. It is probably of the same age as the *Bonaventure Formation*.

Intrusive Rocks.—Important intrusions of plutonic rocks took place during the Devonian in eastern Canada; the earliest appears to have been that of serpentines, peridotites, and allied rocks. The serpentine intrusives stretch the whole way from Newfoundland through Quebec^{25 114 119} to Georgia, and cut rocks of Upper Cambrian, Ordovician, and Silurian age¹¹⁹. They are supposed to be later than the earliest Devonian. The serpentines are of special importance, because of their associated deposits of asbestos, chromite, and talc.

The asbestos veins (see 'Economic Geology') are chiefly worked in the Thetford and Broughton districts^{283 467}. The so-called Thetford Series^{25 97} of intrusives consists chiefly of peridotite, serpentine, gabbro, and pyroxenite, with limited areas of granite and aplite; the bodies of igneous rock take the form of batholiths or intrusive sheets, showing zones of decreasing basicity from the centre outwards and from the base upwards.

At a somewhat later date in Devonian times there took place the intrusions of highly alkaline plutonic and dyke rocks in the Monteregian Hills^{81 85 122} of **Quebec**; these igneous masses form stocks, or laccolites, dykes, or volcanic necks, and fragments of fossiliferous Oriskany (Lower Devonian) limestone are enclosed in the igneous breccia at Mount Royal. A camptonite dyke of this series cuts the serpentines at Eastman, Quebec. Two distinct types of rock are found associated—nepheline-syenite and essexite—with a considerable range of modifications. Mount Royal, Montreal³⁵⁶, consists of a plug of essexites intruded into Ordovician beds causing metamorphism⁵⁸⁴ and followed by intrusions of nepheline-syenite, camptonite, and other igneous rocks.

Along the main axis of **Nova Scotia**¹⁴⁶ there occurred about this time a great intrusion of granite, the main mass occupying the south-western part of the province, and extending as far east as Halifax, with a length of about 115 miles, and a width of about 30 miles. The granite batholiths form the core of the Cobequid and South Mountains.

Devonian granites also form the axes of the southern and northern highlands in **New Brunswick**¹⁴⁰, but most of these intrusions are late Devonian or Carboniferous in age.

Tectonic Disturbances.—The whole of Acadia suffered great crumpling and disturbance in late Middle Devonian times, and after elevation had taken place it was considerably eroded before the deposition of the Lower Carboniferous (Mississippian). This folding was of great extent and importance, and the region affected stretches from the west of Newfoundland²⁸⁹ through Cape Breton Island, Nova Scotia, New Brunswick, Maine, and probably New England, and includes the Gaspé Peninsula of Quebec. Farther south its effects are obscure or perhaps it died out. The above described igneous intrusions were a concomitant phenomenon. Blackwelder⁵⁷ has termed it the *Brunswickian epoch*, but it is generally called the Acadian Revolution²⁸⁹. The angular unconformability of the basal Lower Carboniferous strata in relation to the Knoydart Formation in Nova Scotia is evidence of the disturbance¹²¹.

Newfoundland.—In south-western Newfoundland plant-bearing beds of early Devonian age, containing species of *Drepanophycus* Goppert, and *Tamiochrada* White, have been recently discovered⁵²³, and some of the metamorphic rocks, previously supposed to be Pre-Cambrian, are now considered to be Devonian. Lower Devonian marine fossils (*Spirifer*, *Favosites*, *Camaronocrinus*) have been found also in the red sandstones, shales²⁸⁹, and conglomerates of the St. George Peninsula, and are closely related to those from Dalhousie, New Brunswick²⁹.

(2) **LOWLANDS OF THE ST. LAWRENCE.**—The Devonian in **Ontario**¹¹⁸ succeeds the Silurian, and like it bears a great resemblance to that of New York¹⁴⁹, having been deposited in the same sea, and connected with the gulf to the south, but not open to the Atlantic.

The classification put forward by Stauffer¹¹⁸ for south-western Ontario is as follows :—

{ Port Lambton Beds (probably=Portage and Chemung).
upper { Huron Shale (probably—Genesee Shale).

Middle	{	Hamilton Formation.
		Delaware Limestone.
		Onondaga Limestone.
		Oriskany Sandstone.
Lower	{	Helderbergian (wanting, or possibly represented in part by the Detroit River Series).

The development of the system is not quite identical with that of New York, where most of the divisions first received their names. The lowest formations of the system are doubtfully represented, and the Detroit River beds have equivocal faunal relations¹¹⁸.

The *Oriskany* is a sandstone lying unconformably on the Silurian dolomites, and is seldom more than 25 ft. thick in Ontario.

The *Onondaga* in Canada rests unconformably on the beds below, and varies much in lithological character and thickness. The limestone, of which it is largely composed, is frequently cherty, and in places contains nodular masses of chert⁴⁵⁹. It is rich in organic remains, and its average thickness is stated to be 150 ft. Petroleum is obtained from this horizon.

The *Delaware Limestone* is at the bottom of the Hamilton, and identical both lithologically and faunally with the Delaware limestone of Ohio. It has a thickness of 50-70 ft.

The *Hamilton Formation* consists of alternating shales and limestones with a rich typical fauna^{406 406a}, and has a thickness of 280-550 ft., or sometimes more.

The Upper Devonian beds in Ontario consist of about 200 ft. of black shale, and contain some plant-remains. These shales are known as the *Huron* or *Genesee Shales*, and are followed at Port Lambton by greenish arenaceous shales with fish-remains corresponding to the Portage-Chemung beds of the eastern states of the U.S.A.

There is a noticeable difference between the Devonian faunas of Ontario and those of the typical deposits of New York, but they both belong to the so-called 'Eastern Continental area'¹¹⁸, which is distinct from that of Gaspé and New Brunswick and from that of Manitoba (Interior Continental area).

The Oriskany fauna is a southern and eastern fauna, and has affinities with the Lower Devonian of Brazil and South Africa. According to Williams the Oriskany fauna is equivalent to the lowest arenaceous Devonian fauna of Europe (Gedinnian and Coblenzian).

The Onondaga fauna is composed of a large number of elements. Corals are the most abundant and characteristic fossils, and are marked by strong European relationships. Gastropods are rather abundant, and cephalopoda are important; trilobites are fairly abundant, and bryozoa and brachiopods are well represented.

The Delaware Limestone is essentially the western equivalent of the Marcellus Shale of New York, and the fauna is transitional between the Onondaga and Hamilton. The fauna of the latter is divisible into several faunules, each with a typical assemblage; the fossils are extraordinarily abundant, and include many corals, bryozoa, and brachiopods common to the same formation in New York. The Upper Devonian contains few definite fossils but many conodonts.

The petroleum-bearing strata of this system, which are of great economic importance, are chiefly of Onondaga age^{72 118} (see 'Economic Geology').

(3) CANADIAN SHIELD.—South and south-west of James Bay on the Abitibi River, Moose River, etc., and at other places round Hudson Bay, outliers of

bituminous limestone have been recognised on the Archaean protaxis, some of which yield petroleum. They are equivalent to the Onondaga and Hamilton formations, and were deposited at the north end of the sea which stretched up from the south. On the Moose River there are large beds of gypsum.

(4) INTERIOR CONTINENTAL PLAIN.—The Devonian formations outcrop along the western border of the protaxis, and stretch through Manitoba from beneath the Cretaceous escarpment to the Arctic Ocean, spreading out over a large area from Lake Athabasca³⁴⁵ to Great Slave Lake^{97 178 198 376}, and to Great Bear Lake⁸⁵⁵ and beyond. In the Lake Winnipegosis and Lake Manitoba districts^{98 404} the beds consist of limestone (Upper Devonian), dolomites (Middle Devonian), and red shales (Lower Devonian), in all 500 ft. thick, and overlie the Silurian conformably. They abound in organic remains, and the fossils include *Stringocephalus burtini*, *Rhynchonella cyboides*, *Stropheodonta interstitialis*, and other well-known European species⁴⁰⁴. This fauna is widespread in Alberta, Saskatchewan, Athabasca, and in the Mackenzie⁴⁰³ and Yukon regions; it belongs to the Cordilleran sea, which was separated from the Eastern sea till a late Devonian period. In the Great Slave Lake region the Devonian limestones and dolomites, which lie along the western side of the lake and include representatives of the Middle and Upper divisions³⁷⁶, are frequently full of petroleum^{98 300 376}. In the Mackenzie River Basin^{178 193 a 205 592} the Middle and Upper Devonian, which are represented by limestones and dolomites with characteristic fossils⁴⁰³, exhibit a remarkable horizontality. The Portage fauna of New York, with *Buchiola retrostriata*, is here found in greyish shales and extends into the Yukon and Alaska.

(4a) ARCTIC ARCHIPELAGO.—Marine Lower Devonian fossiliferous beds of a Helderbergian type^{644 645}, and Upper Devonian possessing the Chemung facies, have been found in Ellesmereland^{612 646 646a} and elsewhere^{162 172}.

(5) CORDILLERAN REGION.—The same type of Devonian prevails here as in the Interior Continental Plain. Along the Bow River the Silurian is succeeded by several thousand feet of limestones and shales, and in the Cascade Belt, Purcell Range, and Fairholme Mountains, cherty dolomitic limestones occur containing Devonian fossils, corals, and brachiopods. The thermal sulphur springs at Banff^{98 335} are located along a strike fault in the Devonian limestone, which here grades up into the Carboniferous. The Devonian is found all along the Rocky Mountain system, and on Lake Minnewanka, near Banff³⁸⁶, is represented by the *Minnewanka* (=Banff) Limestone^{245 299}, 2000-2500 ft. thick, containing an Upper Devonian fauna, including *Spirifer whitneyi*, *Productella coloradoensis*, *Schizophoria striatula*, etc., closely related to that of Colorado and New Mexico. In the Crow's Nest Pass^{387 415 571} the Devonian and Carboniferous limestones, having similar characters to those in the Banff area, have been thrust over the Upper Cretaceous to the east as a huge fault block. In the Purcell Range Upper Devonian beds²⁸² contain typical fossils. Farther to the south a series of mainly calcareous beds of Devonian age occurs in the Windermere area²⁸², and an Upper Devonian fauna of brachiopods related to that of the northern Rocky Mountains is found in the upper part of the series. In the Harrogate Canyon⁸⁴⁹, on the Columbia River, Middle and Upper Devonian fossiliferous limestones are present. In the Jasper Park area along the Athabasca River^{289 318 345 426} these Devonian limestones are well developed and contain a rich similar fauna²⁸⁹. In places there are also black shales containing *Styliolina*⁶³² and the Naples⁵⁹⁷ fauna of New York. In the Peace River area⁸⁰⁰ the Devonian consists of limestones, some of which contain an abundant Middle and Upper Devonian fauna of corals and brachiopods. The oil-

bearing rocks on the Lower Mackenzie River²⁰⁶ and Great Slave Lake^{385 876} are referred to the Middle and Upper Devonian and consist of limestones and dolomites, containing abundant brachiopods⁶⁶⁷ and corals⁶⁶⁹.

On the Yukon-Alaska boundary⁹⁶ Middle Devonian limestones with a typical marine fauna are found resting on the Silurian limestones, and either overlain by the Carboniferous limestones or by shales and cherts with plant-remains, which are possibly of Upper Devonian age and may represent the more northern calcareous deposits. The Devonian limestones^{246 368 389} lie with a great unconformity on the Cordilleran geosyncline, having been deposited by the transgression of the Devonian sea, and this great stratigraphic break is traceable also in Missouri and in the Grand Canyon of Arizona.

Carboniferous

(1) ACADIAN REGION.—The Carboniferous beds have a generally similar and uniform development throughout the eastern provinces⁴⁹³ and Newfoundland, and form one of the most important groups of deposits in Nova Scotia, New Brunswick, and Cape Breton Island, containing the chief coal-fields of the Atlantic region. Over nearly the whole of New Brunswick, Prince Edward Island, and much of Nova Scotia the rocks lie flat or with only gentle undulations, though locally they have been tilted and dislocated. They mostly rest on the Cambrian or pre-Cambrian rocks. The fullest description¹⁶⁴ of the fauna and flora is given in Sir J. W. Dawson's '*Acadian Geology*,' but the classification of the beds has been much modified in accordance with later researches²⁸⁸.

In Nova Scotia the *Riversdale-Union Series* of beds, which is about 10,000 ft. thick and covers a large area, has been classed by some geologists with the Devonian⁸² of fresh-water or estuarine origin. It consists of grey, red, and purplish shales with some sandstone beds. The Union Beds, which are the highest, are chiefly bright red in colour and almost barren. The fauna and flora of the whole Riversdale-Union Formation indicate (according to Ami¹⁵⁹) that the beds are referable to the Middle Carboniferous³². The structural relations and age, however, are a matter of dispute or uncertainty.

There is another series of beds in Nova Scotia and on Cape Breton Island⁸³⁷ known as the *Horton Series*^{34 223 257}, the age of which has been regarded by some geologists as Devonian rather than Carboniferous. The deposits are of estuarine or littoral origin, and consist of black shales and sandstones containing plant-remains, especially *Lepidodendron corrugatum* and *Aneimites acadica*, together with many fish-remains, the evidence of which indicates that they should be regarded as Lower Carboniferous, and approximately correlated with the Pocono Formation of the eastern United States, the Albert Shales of New Brunswick, and the Calciferous Sandstone of Scotland. Corresponding beds of the same age and type occur in Spitsbergen, Bear Island, and Greenland.

This Horton Series of Nova Scotia is succeeded by the marine limestones, dolomites, gypsum, and bright-coloured marls of the *Windsor Formation*^{34 223 257}, which are locally much folded and faulted. The fauna is, on the whole, like that of the Carboniferous Limestone of Europe, but that contained in the upper dolomites is peculiar. The Windsor Formation is correlated by Bell²⁵⁷ with the Viséan of Europe. The beds of gypsum and salt²⁶⁷ are of great commercial importance⁸⁸. The same beds extend into the Magdalen Islands⁸⁷⁸. In the Carboniferous succession on Cape Breton Island⁸⁸⁷, there is a basal conglomerate followed by marine limestones, shales, and beds of gypsum, corresponding to the Windsor Formation, and these are succeeded by the Pennsylvanian as described below. In the Arisaig and Joggins regions^{26 85 121 164} this Mississippian division of the Carboniferous is likewise developed. Uplift and erosion occurred before the deposition of the later Carboniferous

beds, and are marked by unconformities in many parts of Nova Scotia and New Brunswick.

The *Pennsylvanian Group*³⁵ of Beds overlies the Windsor Formation in Nova Scotia after this decided break in the succession, and is composed of fresh-water or estuarine deposits. Under the older classification it was divided into Millstone Grit, Productive Coal Measures, and Permo-Carboniferous. The Millstone Grit, or Early Pennsylvanian, is over 4500 ft. thick in the Joggins section; the Middle Pennsylvanian or *Joggins Formation* is over 6800 ft. thick, and comprises the Productive Coal Measures. The Joggins section³⁵ shows the early Pennsylvanian resting on the Windsor Formation, and is composed of conglomerate, prevailing red, grey sandstone, and shale, with thin coal-seams. This is succeeded by a barren red shale division and the typical Joggins Formation¹⁶⁴ of sandstones, shales, and productive coal-seams, seventy in number. Organic remains are abundant, and erect trees are a feature, and the amphibian remains are of much interest^{164 639}. The flora is of the usual Upper Carboniferous type. Bell²³⁸ has proposed a new classification of the Carboniferous beds in Nova Scotia, and gives a different correlation, including beds formerly placed in the Permian. The beds succeeding the Windsor Formation are correlated by him with the Lower, Middle, and Upper Westphalian of Europe. The northern facies in Nova Scotia is different from the southern facies. The southern facies has its highest beds, named the *Stellarton Series*, which Bell places on the horizon of the Upper Westphalian. But the *New Glasgow Conglomerate* of the northern facies, which he correlated with it, is generally referred to the Permian (see below). The *Stellarton Series* of the southern facies is there the coal-bearing formation. All the Carboniferous Rocks of the Northumberland Strait area are fluvial or fluvio-lacustrine. Several movements during their deposition can be recognised, and Bell²³⁸ describes three.

There are three chief coal-fields, the Cumberland (including the Joggins) and Pictou in Nova Scotia, and the Sydney in Cape Breton Island²⁷⁴. The Sydney coal-field^{86 274} in Cape Breton Island shows a total thickness of Carboniferous strata of about 12,600 ft., and by reason of a series of low folds of the beds or indentations of the coast is naturally divisible into six coal basins. The fossil flora has been described by Bell⁴⁶³. The coal-seams vary in thickness and character, but in the Productive Coal Measures (Middle Pennsylvanian) there are usually twenty-four seams of coal with a total average thickness of 46 ft. The Coal Measures and Millstone Grit divisions together amount to a thickness of about 5600 ft.

In **New Brunswick**^{161 268 290} the *Albert Shale*^{33 72 73} form the basal series of the Carboniferous, but are referred by some authors to the Devonian¹¹⁵. They are probably on about the same horizon as the Horton Series of Nova Scotia, already mentioned, and consist of thinly bedded dark slates, sometimes calcareous, with limestones, sandstones, and oil-shales which are rich in hydrocarbons. The petroleum and gas of the Stony Creek field, near Hillsborough, are derived from sandstone members of this formation^{72 268 324}. The typical plants of the Horton Series occur also in these beds, and fish-remains are abundant in places in the shales, especially members of the genus *Palæoniscus*⁴⁴⁴. Red conglomerates and limestones with beds of gypsum lie above them, and represent the Lower Carboniferous, while characteristically grey beds, non-calcareous, and associated with thin coal-seams, correspond to the Pennsylvanian.

In **Quebec** the only probable Carboniferous rocks are certain conglomerates and sandstones in the Gaspé Peninsula belonging to the *Bonaventure Formation*^{29 149}, part of which is probably late Devonian, as already mentioned. These beds extend down to the northern part of New Brunswick.

In Newfoundland²⁵⁵ certain beds in St. George's Bay are probably equivalent to the Windsor and underlying formations of Nova Scotia, and the Pennsylvanian also seems to be represented^{149 529}. The Carboniferous rocks occupy a large area on the western side of the island. In central Newfoundland Lower Carboniferous strata containing plant-remains occur in the Buchans district; the beds with *Psilophyton*, *Sigillaria*, etc., at Cape Rouge are also referred to the Carboniferous. The succession of Carboniferous rocks in St. George's Bay, which has been described in detail by Hayes and Johnson^{529 532}, comprises beds of Mississippian and Pennsylvanian age (Lower and Upper Carboniferous), in all about 12,000 ft. thick. The Lower Carboniferous portion comprises sandstones and shales containing a few poorly-preserved plant-remains (*Catamites*, etc.); there are also gypsiferous red shales with a thin limestone near the top containing a small fauna, chiefly of brachiopods, related to that of the Windsor formation, and it is followed by more marine shales and thin limestones containing Windsor species of mollusca and brachiopods. The Upper Carboniferous (Pennsylvanian) comprises sandstones, conglomerates, arkoses, and shales with seams or lenses of coal varying much in thickness. The beds contain plant-remains (*Sphenopteris*, *Lepidodendron*, *Catamites*). The whole series of beds is much crumpled, shattered, and faulted⁵²⁹. The principal coal-seams in the St. George's coal-field number nine, and are stated to range from 1 ft. 2 in. to 4 ft. 6 in. in thickness, but the field is much faulted and the quality of the coal is poor⁵³². The coal-seams occur in the higher part of the Carboniferous system on the south-east side of St. George's Bay, and probably belong to the same coal-field as do those in New Brunswick. The Appalachian⁵⁷ revolution in post-Carboniferous times affected all Acadia, including Newfoundland, and was followed by a long period of erosion, for the peneplain then produced was not apparently again submerged till late Pleistocene times.

(2) LOWLANDS OF THE ST. LAWRENCE AND INTERIOR CONTINENTAL PLAIN.—No Carboniferous rocks are known over the greater part of these regions, but on the western edge of the protaxis they are strongly developed in Alberta and in the eastern parts of the Rocky Mountains and foot-hills between the Devonian and Cretaceous (see 'Cordilleran Region').

(3) ARCTIC REGIONS^{149 163 169 172}.—Lower and Upper Carboniferous marine limestones, with characteristic fossils, occur in Ellesmereland⁶¹², Grinnell Land, and elsewhere.

(4) CORDILLERAN REGION.—In the Rocky Mountains of **Alberta** the Carboniferous is found to succeed the Devonian conformably, and is largely composed of limestones and shales, but locally has a considerable development of lavas and tuffs. It reaches a thickness of 5000-7000 ft. Lower Carboniferous (Mississippian) limestones are present with a characteristic marine fauna of brachiopods, etc., and the Upper Carboniferous (Pennsylvanian) is also developed. This type of development is found in the Bow River region, and in the Crow's Nest⁴¹⁵ and Kootenay Passes. In the Banff area^{245 318 335} the Lower Carboniferous (Mississippian) is called the *Banff Formation*, and consists of dark grey or black shales, becoming calcareous above and abundantly fossiliferous, the majority of the fossil species occurring also in this horizon in the United States. It is followed by the *Bundle Limestone*, the upper part of which is referred to the Pennsylvanian (Upper Carboniferous), but fossils in it are rare. The succession in the Crow's Nest Pass^{867 415} agrees with that near Banff. Farther north, in the Jasper area^{299 318 425}, the succession is like that near Banff, the lower or *Banff Shales* containing a similar Lower Carboniferous fauna. The *Bundle Limestone* is richly fossiliferous, and is followed by the *Rocky Mountain Quartzite*, which is here considered to be of Permian

age²⁴⁵ (see below). In the *Kootenay Valley* the Upper Carboniferous is known as the *Slocan Series*^{260 340 357}, and consists of argillites and limestones with typical fossils.

In the Kamloops area of **British Columbia**⁵², farther west, the Upper Carboniferous is represented by part of the *Cache Creek Formation*^{31*}, 9500 ft. thick, containing *Fusulina* in the limestones; along the coast and on the Interior Plateau similar limestones, 3000 ft. or more thick, and largely composed of *Fusulina*, succeed volcanic rocks and argillites, which reach in places a thickness of 5000 ft. or more. In the Cariboo area²⁴⁶ the Lower Carboniferous, consisting of cherts and limestones with some volcanic rocks, rests directly on the Pre-Cambrian Cariboo Series and probably forms part of the *Cache Creek Series*^{296 373} which is widespread in British Columbia and extends northwards into the Yukon and southwards into the State of Washington, U.S.A., and probably even into California. A considerable fauna has been recorded⁸⁷³ from part of it, indicating that at least the upper part is of Permian age (see p. 339), as is shown by the cephalopods⁴³⁸. In the south-west corner of British Columbia, near Hope on the Kettle Valley Railway²²⁸, the same Cache Creek Formation consists of andesitic greenstones, cherts, and argillaceous sediments, more or less metamorphosed later by intrusive rocks. In the Bridge River area^{100 101} rocks of this lower series with cherty quartzites have suffered much alteration, and near Prince Rupert they are partly represented by schists. In the Peace River area³⁰⁰ we find the Lower and Upper Carboniferous represented chiefly by fossiliferous limestones. On the Liard River in the **Yukon** there are limestones and shales²¹⁸ with an abundant Lower Carboniferous (Kinderhook) fauna.

On the Yukon-Alaska boundary^{96 103} the Carboniferous has two lithological facies, one represented by shales and the other by limestones and cherts, but both apparently occupying the same stratigraphical position, Mississippian and Pennsylvanian fossils being abundant in them. It was during the Carboniferous period that the long-continued though intermittent vulcanicity of the Yukon region commenced, and was prolonged into Cretaceous times¹⁰³ (see below).

In the south part of *Vancouver Island*^{92 227} there is a series of slates and quartz-schists, apparently the oldest rocks in the island, which are provisionally referred to the Carboniferous. These (the *Leech River Formation*) are at least 5000 ft. thick²²⁷, and are overlain by the *Malahat Volcanics* which are largely fragmental and estimated as 2500 ft. in thickness. These formations are closely folded into a north-easterly-dipping homocline, and may be correlated with the Cache Creek Formation³⁷⁸ of the mainland. Overlying them are the Lower Mesozoic altered rocks of the Vancouver Group (*q.v.*).

All through the Cordilleran region in the western geosynclinal belt the Central Russian type of fauna prevailed, the Upper Carboniferous being marked by marine limestones formed almost entirely of *Fusulina*. In eastern Canada, on the other hand, the West European development is found, the beds being fresh-water, terrestrial, or estuarine, and *Fusulina* limestones are absent.

Permian

(1) ACADIAN REGION.—Younger than the Productive Coal Measures in the Carboniferous area around the Gulf of the St. Lawrence are the thick masses of conglomerates, sandstones, and shales extensively developed along the shores of Northumberland Strait²³⁸ and over Prince Edward Island¹⁴⁹. In some places they succeed the Carboniferous without any apparent unconformity, but in others there has first occurred an uplift and erosion. These beds include the *New Glasgow Conglomerat*^{36a 238}, which occurs along the

Nova Scotian and New Brunswick coasts of Northumberland Strait. The beds consist largely of red sandstones comparatively undisturbed, and have a total thickness of not less than 10,000 ft. Plant-remains with a general Upper Carboniferous stamp have been found in them, but a genus of Permian reptiles is known from the highest beds. Considerable difference of opinion exists as to the precise stratigraphical correlation of these deposits. The higher beds with similar lithological characters are usually referred to the Triassic (see below).

In the Joggins section, Nova Scotia, the so-called *Shulie Formation*, which must at any rate be of late Pennsylvanian age, may likewise be referable to the Permian. It consists of conglomerates, sandstones, etc., about 2100 ft. thick.

The flora of the '*Little River Group*' in New Brunswick, which consists of sandstones and shales, seems to indicate an Upper Carboniferous or Permo-Carboniferous age, but some geologists attribute the beds to the Devonian.

For the most part, the Permian period in Canada, especially in the east, was marked by emergence and folding, constituting the so-called *Appalachian epoch* of orogeny. This is one of the best-known periods of crustal disturbance in North America, and the region affected stretches from Newfoundland to southern New England, but apparently the disturbances did not extend far westward. The deposits which accumulated at this time are mostly fresh-water or brackish in origin, and no purely marine calcareous beds were formed.

(2) CORDILLERAN REGION.—The *Rocky Mountain Quartzite*, which succeeds the Rundle Limestone, was previously referred to the Upper Carboniferous, but it is found to contain near Banff³⁸⁵ the Permian gastropod *Euphemus carbonarius*²⁴⁵. This formation also occurs in the Crow's Nest Pass⁴¹⁵ at the top of the Palaeozoic.

There is a peculiar conglomerate at least 700 or 800 ft. in thickness along the Yukon-Alaska boundary⁹⁶, possessing the general characters of a tillite with boulders up to 4 ft. in diameter, but no striated pebbles have been found in it, though faceted pebbles are somewhat plentiful. It overlies the Devonian-Cambrian limestones and dolomites, and appears also to overlie Carboniferous shales, and to correspond stratigraphically to the Nation River beds of the same area, which contain either Artinskian or Gschelian fossils, and may be partly Permian. It is therefore thought to be of Permo-Carboniferous age, and may correspond to the Talchir and Dwyka conglomerates of India and South Africa, and be likewise of glacial origin.

On the west coast of Vancouver Island²⁷² a fossiliferous Permian limestone has been found, and the Permian bryozoa⁴¹⁴ from a limestone in Strathcona Park are said to resemble those in Timor. As above mentioned, the Upper part of the *Cache Creek Series*^{296 373} of British Columbia must be put in the Permian, for it contains such typical ammonoids as *Propinacoceras*, *Agathiceras*, *Adrianites*, and other cephalopod genera, as well as species of brachiopods found in the Permian of the Urals. In the Marble Canyon of the Fraser River the typical Permian genera of foraminifera, *JSchtmgerina*, *Yabeina*, *Neoschwagerina*, have also recently been discovered⁶³¹.

Trias

(1) ACADIAN REGION^{149 164 231}.—Along the south-east coast of the Bay of Fundy and on the opposite New Brunswick side there are red shales, red sandstones, and conglomerates, which are associated with traps (diabase) in Annapolis and King's Counties¹⁴⁶. These traps are sometimes ashy, sooriaeaceous, or amygdaloidal, and occur in well-bedded flows, often with columnar structure. The amygdaloidal traps of Blomidon¹⁶⁴ and of the North Mountain belong to the same series. The sedimentary beds in places have yielded

plant-remains (*Walchia*, etc.), and are probably the northern extension of the 'Newark Series' of New Jersey^{34 74}. These beds were deposited in one of the narrow troughs which were developed in the eastern part of North America, and rest with a strong unconformity on the older rocks. No marine deposits are known in this region. These Triassic beds, which are fluvatile or lacustrine in origin, are the only Mesozoic sediments in eastern Canada, and until Pleistocene times no further deposits of any kind are known to have accumulated in this region. The long period of denudation under sub-aerial conditions which has lasted practically till to-day had by this time set in over eastern Canada. The Triassic rocks in this region²⁸¹ are folded and faulted, a monoclinical structure being developed with a prevailing north-westerly dip, interrupted by low folds and traversed by numerous faults, mostly trending east and west or north-east and south-west.

(2) ARCTIC REGIONS.—Mesozoic rocks, consisting largely of sandstones with shales, schists, and limestones, occasionally fossiliferous, are known from Ellesmere Island⁶¹² and many other parts of the Arctic regions, and include beds of Triassic age. In Ellesmereland⁶⁷⁶ Triassic rocks with a considerable marine fauna have been discovered along the coast.

(3) CORDILLERAN REGION.—In the Rocky Mountains and the eastern foot-hills there are now known to be Triassic beds of marine origin, and in Banff²⁴⁵ and Jasper Park³¹⁸ areas these consist of black limestones, dolomites, and black shales forming the *Spray River Formation*. The latter has yielded only some obscure fish-remains, a few lamellibranchs, and a *Lingula*, near Minnewanka. The shales were termed the 'Upper Banff Shales'³⁷ and were formerly referred to the Permian; they lie conformably on the *Rocky Mountain Quartzite* of Permian age. In the eastern foot-hills of the Rockies there are now known to be fossiliferous marine Upper Triassic beds like those on Vancouver Island, yielding *Monotis*, *Halobia*, *Trachyceras*^{139 226 439}, etc. In the western half of the Cordilleran region, and in the southern portion of the interior of British Columbia (e.g. Thompson River Valley¹⁰⁷), and all through central British Columbia, there is an immense series of volcanic rocks, chiefly consisting of basalts, diabbases, porphyrites, and agglomerates. These are apparently of submarine origin, and are associated and intercalated with limestones, argillites, etc., forming the *Nicola Formation*¹⁶⁵, 13,500 ft. thick on the Thompson River. The sedimentary deposits contain crinoids, lamellibranchs, etc. Thick fossiliferous Triassic shales also occur in the Cascade Range. In the Bridge River area²⁷⁰ the thick series of conglomerates, sandstones, and shales with lenses of limestone, and having in its lower part great thicknesses of basalts and andesites, has yielded in the limestones corals, brachiopods, and mollusca^{408 409} of Upper Triassic age. These beds, which are termed the *Cadwallader Series* in the Bridge River area, have yielded species of corals of the genera *Isastræa* and *Montivaltia*, and lamellibranchs of the genera *Myophoria*, *Megalodon*, *Pleuromya*, etc., of south-eastern types⁴⁰⁸. The Trias is represented in the *Peace River area*^{209 300 421} by limestones, shales, and calcareous sandstones 3000 ft. thick, containing ammonites⁴²¹ (*Prtrachyceras*, *Nathorstiæ*, etc.), brachiopods, and some lamellibranchs (*Pseudomonotis*, etc.); on the Stikeen and Hard Rivers similar rocks occur. The *Dawsonites* zone of the Upper Triassic, containing *D. canadensis* Whiteaves, is found on the Liard River, and has not been recognised farther south in North America. In the Rossland area¹⁸⁶ there is a large volcanic group of rocks of augite-porphyrates and agglomerates, resembling the Nicola lavas, but there are also masses of intrusive serpentine and pyroxenite provisionally referred to the Triassic. In the Tulameen district²²⁹, B.C., there is a great development

of lava-flows interbedded with true sediments, and the whole *Tidameen Group* is correlated with the Nicola Group¹⁸⁵. In the Cassiar district B.C.^{581 583}, the *Dease Series* is partly of sedimentary origin and partly volcanic; Permian and Triassic fossils have been recorded from it, but it may include older rocks, and 'probable Silurian' fossils are stated to have been found in it. The pre-batholithic altered rocks of Britannia beach, New Westminster⁸⁸⁸, and on the islands between Burke and Douglas Channels⁸⁵⁹, are probably also of Triassic age.

In the southern **Yukon**^{432 450} at various points the massive limestones, 2000-3000 ft. thick, with some interbedded elastics, which were formerly referred to the Carboniferous, are now found to be of Triassic age, for they have yielded Noric and Carnic ammonites (*Juvavites subinterruptus* Mojs., etc.) and various mollusca, including the lamellibranch *Halobia ornatissima* Smith, and the Noric *Pseudomonotis subcircularis* Gabb, together with corals—*Isastrea*, etc. The beds containing *Ps. subcircularis* occur along the eastern side of the Rocky Mountains of British Columbia and the Yukon in a more or less continuous belt. In the Carmacks district and Laberge area^{344 450} in the Yukon there are tuffaceous sandstones and breccias with several hundred feet of limestones underlying the Jurassic Laberge Series (see below), but they are unfossiliferous. They are provisionally referred to the Trias, and termed the *Lewes River Series*.

In the northern part of **Vancouver Island** are found marine Upper Triassic limestones and argillites, containing *Pseudomonotis subcircularis*⁴⁰⁹ and other fossils, and have volcanic beds associated, forming part of the composite *Vancouver Group*^{120 427}. It is only the lower part of this group of beds which can be referred to the Triassic, such as the *Sutton Limestone*²⁷³ on Cowichan Lake, the rest being now put in the Jurassic (see below). In addition to sedimentary deposits the Vancouver Group is largely composed of volcanic tuffs and lavas, chiefly basic, which are often metamorphosed into schists. Probably these may be correlated with the Nicola Group of the mainland. The same set of beds occurs also in the **Queen Charlotte Islands**³⁴⁵, and in the coastal islands^{117 226 359a}. On Texada Island^{128 226} in the Strait of Georgia Triassic limestone occurs as well as great deposits of magnetite^{213 279} (see 'Economic Geology').

The Triassic marine transgression seems to have started far to the south in California, and to have worked northwards, gradually extending its area, so that only the higher Triassic beds were deposited in British Columbia. But all the beds belong to the same zoo-geographical province, and in California the Mediterranean facies is strongly suggested^{226 409}. The close of the Triassic period in the Cordilleran region was marked by a pronounced elevation, together with a considerable folding of the rocks, which is specially noticeable in Alaska.

Igneous Rocks.—A great outpouring of igneous material is one of the most striking features of Triassic times in the Pacific regions^{165 272}, extrusive and intrusive masses forming batholiths of various petrographical types and large dimensions being present throughout most of the area west of the Selkirk Range. The volcanic activity continued in many districts into Jurassic and even into Cretaceous times^{3 330}; such was the case in the Bridge River area^{100 101 270}, where an immense thickness (+12,000 ft.) of andesitic lavas and breccias is followed by conglomerates, sandstones, slates, argillites, etc., with a few andesitic rocks, the upper beds of the series containing marine fossils like those of the Cretaceous of the Queen Charlotte Islands Series (see below).

Jurassic

No marine Jurassic is known on the east coast of America north of Maryland, but the lignite fire-clay deposits on the Mattagami River⁶²¹ and its neighbours on the James Bay Slope of northern Ontario are proved to be Mesozoic and probably Upper Jurassic or early Cretaceous in age by the plant-remains in them. In the Arctic archipelago (Grinnell Island and Prince Patrick's Island) undoubted Jurassic beds occur, yielding remains of *Ichthyosaurus*¹¹² and other fossils. The greater part of the continent was probably elevated above the sea during this period, forming Neumayr's so-called 'Nearctic Continent.' The invasion of the sea into the western part of North America in Middle Jurassic times brought a fauna into the Rocky Mountain region extending from the coast to the foot-hills having a uniform character of a boreal type, as Neumayr recognised long ago.

INTERIOR CONTINENTAL PLAINS.—In the western part of the Interior Continental Plain at Fernie, B.C., south of Calgary and east of Banff^{262 385 338 585} and in the Jasper Park area³¹⁸, black and brownish fossiliferous shales (*Fernie Series*), 1000 ft. thick, of marine origin, are found overlying 500 ft. of sandy argillites, but decrease in thickness eastwards. In the Crow's Nest Pass⁵⁷¹ they rest with a basal conglomerate on the Palaeozoic rocks.

CORDILLERAN REGION.—On the Cascade River in British Columbia the same *Fernie Series*³¹⁸ is 1500 ft. thick, and retains its black shaly character, though limestones occur in places near the base. It is traceable northwards to the Athabasca River, and contains a characteristic marine fauna^{411 423 586}—*Peltoceras*, *Cardioceras*, *Trigonia*, *Astarte*, *Pleuromya*, *Lima*, and many other fossils, including reptiles and fish. The upper part is arenaceous, and passes up conformably into the sub-aerial sandstones of the Kootenay Formation (Lower Cretaceous).

In southern and central British Columbia the Triassic volcanoes which poured out the lavas, etc., of the Nicola Formation continued active into Jurassic, and indeed into Cretaceous, times. A thick series of these rocks occurs on the forty-ninth parallel in the western geosynclinal belt³ and in the Thompson River Valley (*Spence Bridge Volcanic Group*)^{10 7}. In the Ashcroft²⁶⁶ and Cariboo areas and along many parts of the Fraser River Valley there are fossiliferous Jurassic beds, which have been described by Crickmay²⁶⁶, while in the extreme south-west of British Columbia in the Coquihalla area²²⁸ there are also slates and volcanic tuffs which have yielded a few mollusca, probably of Upper Jurassic age. In the Salmon River district²⁰⁸ there are thick volcanic agglomerates and tuffs with marine conglomerates, etc., also referred to the Jurassic. The *McLeod Series*^{381 583} in the Cassiar district is a complex assemblage of volcanic fragmental rocks and lava-flows with some sedimentary rocks (sandstones, greywackes, argillites, and quartzites), the whole being intruded by serpentine and granite. The series is correlated with the Jurassic of central British Columbia because of its relation to the Dease Series^{381 583}. In the Bridge River area^{100 101 270} the volcanic series is of great volume, the andesitic lava-flows being the thickest members, but the breccias are about 3000 ft. thick. Peridotites, which have been in places altered to serpentine and contain deposits of chromite, belong probably to the same period of igneous activity in this area.

Along the Grand Trunk Pacific Railway between Prince Rupert and Telkwa^{106 267}, and in the Hazelton district on the Skeena River, there are tuffs⁵, breccias, and andesitic and liparitic lavas associated with conglomerates and other sediments, forming the *Hazelton Series* and containing marine Middle and Upper Jurassic^{240 334} and Cretaceous fossils^{207 240 485} and many

land plants, which show close relations to the Lower Cretaceous (Kootenay) flora. Some black marine shales with thin beds of limestone and sandstone, in which *Gryphaea* has been found in the Peace River area³⁰⁰, are supposed to be of Jurassic age.

The greater part of **Vancouver Island**^{38 92} is composed of more or less altered Mesozoic volcanic rocks (possibly including some Palaeozoic) known as the *Vancouver Group*^{120 227 427}, having an estimated thickness of 20,000-25,000 ft. The rocks are chiefly of a basic nature, the commonest type being a meta-andesite. They are mostly of Jurassic age (but some are Triassic or earlier, as above described), and have intercalated amongst them lenticular masses of crystalline limestone containing Lower Jurassic marine fossils. The volcanic series comprising most of the so-called *Sutton Formation*⁵⁷³ is referred to the Jurassic, but the Sutton Limestone, as above mentioned, is of Triassic age. There is, however, no definite break between the Triassic and Jurassic in this series in the island. In the Sooke and Duncan areas²²⁷ the lower part of the Vancouver Group is called the *Sicker Series*, and begins with a great mass of submarine andesitic lava 3700 ft. thick, followed by tuffs and shales varying from 200 to 3000 ft. Whether it is Lower Jurassic or Upper Triassic is uncertain. In the **Queen Charlotte Islands**^{94 545} similar rocks occur, and the associated fossiliferous sediments show that they belong partly to the Triassic and partly to the Jurassic, the latter beds including numerous species of *Aucella* and of ammonites (*Cadoceras*, *Cardioceras*, etc.). Similar beds occur in Alaska, and to the south of British Columbia in the United States, and it seems that a great inlet of the then existing Pacific stretched also in a south-eastern direction into Wyoming, Montana, and Utah. The correlation of these and later Mesozoic beds on the Pacific coast has been discussed by Goranson²²⁶.

In the **Yukon district**^{54 55 102 103 247} there are thick beds of volcanic ash and breccia and some flows of andesitic lava which are intercalated with Jurassic fossiliferous sediments and form the *Lahege Series*^{99 102 110 450}. This series^{602 640}, consisting chiefly of sandstones and conglomerates, comprises horizons ranging from the Lower or Middle Lias to the Inferior Oolite of the European succession, as proved by its ammonites^{344 450 602}. It varies locally much in thickness and is estimated to range from 2800 to 10,000 ft.

Most of the above volcanic and sedimentary rocks of Jurassic age seem to be anterior to the injection of the great batholiths^{35 9} which are a conspicuous feature of British Columbia and of the coastal islands, and in fact characterise the whole western border of the continent for 1200 miles. These batholiths are frequently composite and represent successive intrusions of rocks of various types, though probably differentiated from the same magma. The period of intrusion is generally regarded as ranging from the Jurassic to the Tertiary, but may have begun in late Triassic times. The major part seems to have been intruded before the Cretaceous, but some of the associated batholithic rocks are undoubtedly of Cretaceous age. The chief one is known as the *Coast Range batholith*^{3 51 53 101 117 120 123 320 344}, for it extends along the whole western coast, being found also on many of the islands, including Vancouver Island and Texada Island¹²⁸ and on the coast beyond Prince Rupert^{359a}, as well as far into the Yukon^{247 271 602} and Alaska. This huge plutonic mass consists of several petrological types and successive intrusions, which range from basic gabbro to acid granite. A definite sequence is sometimes recognisable. In northern British Columbia nine distinct intrusive phases have been recognised⁸²⁰. The prevailing rock is coarse and often gneissoid or even schistose in structure, and is termed a granodiorite; it has produced considerable metamorphism in the surrounding sediments. It is in connection with these batholiths and the volcanic rocks of Jurassic age that most of the

mineral deposits in British Columbia occur. The belts of mineralisation run mostly in a north-westerly direction parallel to the coast in the northern part of the area^{190 296 362}. Minor intrusions in other parts also took place during the same general period, and in the Rossland area¹⁸⁶ there is a considerable batholith (Trail) of granodiorite, as well as a huge chonolith of monzonite accompanied by andesite and latite flows and tufts. The Nelson granite batholith forming the core of the Selkirks was intruded also in late Jurassic times. Probably in connection with these major plutonic intrusions, there occurred the great crustal disturbances which affected the whole Pacific coast, extending inland to central British Columbia, and constituting the *Nemidian*⁵⁷ (or 'Upper Jurassic') revolution or group of orogenic movements by which the Triassic and older rocks west of the Rocky Mountains were broken up by faults and thrown into great folds trending in a general N.N.W.-S.S.E. direction more or less parallel to the present coast-line. The relations between the intrusions of basic and ultrabasic rocks and the tectonic conditions accompanying them have been discussed by Benson⁵⁵⁶.

Cretaceous

(1) ACADIAN REGION.—No definite Cretaceous deposit has been found here.

(2) The CANADIAN SHIELD and LOWLANDS OF THE ST. LAWRENCE were apparently land-areas during this period, and possess no Cretaceous deposits.

(3) INTERIOR CONTINENTAL PLAIN.—The Cretaceous System⁴³ is here widely developed on the west of the protaxis, and is very complex and varied in its development. The Lower⁵³⁹ and Upper Cretaceous are most important formations from an economic point of view, being the great coal-bearing series of western Canada, and as such pass over into the Cordilleran region. The deposits vary much in character in different localities, and the correlation^{539 540} of them is therefore difficult. The break between the Lower (Comanchian of U.S. geologists) and the Upper Cretaceous is much more pronounced than in Europe. In the Interior Plains the lower beds are largely terrigenous or fresh-water in character, but on the Pacific coast and in the Upper Cretaceous of the Interior marine invasions brought in different conditions and faunas. A very complete section of the Cretaceous is seen in the Manitoba escarpment⁵⁹³ which forms the eroded eastern edge of the Great Plains and is represented by a line of hills with a general N.N.W.-S.S.E. trend. It exhibits beds ranging from the Dakota to the Pierre. In the plains³⁰⁶ the beds for the most part lie flat, or have been worn down equally, and show hardly any disturbance away from the foot-hills. There is, however, a broad anticlinal or monoclinal fold trending in a general northerly or north-westerly direction across Alberta²⁶² into Saskatchewan³³⁸, and in south Alberta the strata sink down into a great syncline. In the northern part of the Mackenzie River⁵⁹² basin they have been to some extent involved in the Cordilleran disturbances, as in the foot-hills of the Rockies.

The Lower⁶⁸⁹ Cretaceous is represented by the *Kootenay Formation*, which is absent in Manitoba but well developed in the foot-hills in Alberta³⁵⁷. The beds are chiefly shales with numerous coal-seams^{277 600} and some interbedded sandstones; the formation thickens westwards, being at its maximum thickness (5000 ft.) in the Elk River Valley. It is held by some geologists⁵⁵¹ that the Kootenay coal-measures in the Alberta foot-hills are of Upper Jurassic age, as are their supposed equivalents in Montana and Idaho, and that the Blairmore Conglomerate forms the base of the Lower Cretaceous (see below). The Kootenay Formation is succeeded in Alberta by the *Dakota Formation* belonging to the Upper Cretaceous, and this is the oldest Cretaceous present in Manitoba, where it rests directly on the Devonian. The Dakota consists of sand-

stones of fluviatile or sub-aerial origin containing oil and gas and a rich land flora. It is only 200 ft. thick in Manitoba, but thickens westwards, and is seen on the back slopes of some of the outer ranges of the Rockies. On the Athabaska River the so-called 'Tar Sands'^{1254 345 386 412 635} (*McMurray sandstone*)^{178 189}, which are considered to be of Lower Cretaceous or Dakota age, rest directly on the Devonian Formation, from which the bitumen is believed to have been derived. These sands are in places 200 ft. thick (see under 'Oil' in *Economic Geology'). The fauna⁴¹² of the *McMurray Formation* is predominantly fresh-water, and consists of a few mollusca, some of which show affinities with those of the Blairmore Formation (see below) of the Crow's Nest area in Southern Alberta. The '*Clearwater Formation*' which succeeds the *McMurray* has yielded a considerable number of lamellibranchs⁴¹⁹ and ammonites⁵⁴⁰, indicating marine conditions and an Aptian age.

The higher beds of the Upper Cretaceous are for the most part marine, and are divided into several series in Saskatchewan³³⁸ and Alberta¹⁰⁴, and in the Mackenzie River basin^{178 198 198a}, bearing local names. The marine subsidence carried the sea from the Gulf of Mexico across the interior basin to the Arctic Ocean, and in it were laid down a series of shales and limestones which belong to the Colorado and Montana Groups of the United States. In the Colorado Group the *Niobrara* and the *Benton formations*⁴⁴¹ are the most important divisions. In Manitoba these beds are 300-400 ft. thick, and consist of carbonaceous and phosphatic shales, dolomitic and ordinary limestones, and some clays; they contain *Inoceramus*, *Belemnites*, foraminifera, and other marine fossils. The *Benton Formation*, as represented in Alberta, comprises the *Alberta Shales*, which are divisible into many fossil zones⁴⁴¹ containing marine mollusca. The *Benton Formation*, which underlies the *Niobrara*, includes soft clays carrying colloidal silica; these clays retain water and are therefore important as soils.

The higher or *Belly River Formation*^{262 443} (of the Montana Group) is a northern continuation of the Judith River beds of Montana^{104 166}, and is about 800 ft. thick in Manitoba, where it consists of fossiliferous marine shales⁵²⁶, and spreads through Alberta and Saskatchewan³³⁸, but wedges out east and west, and changes in character. The Montana Group forms the surface rock over nearly the whole Cretaceous area of the Interior Plains³⁰⁶. The *Belly River Formation* contains many valuable coal-seams in the west²⁷⁷, and in parts of Alberta has yielded remains of dinosaurian reptiles. In the eastern part of Alberta and Manitoba it is partly equivalent to a marine formation which is there known as the *Pierre Formation*, but westward the marine deposits are subordinate and shore-deposits predominate^{104a}, so that it becomes essentially a brackish or fresh-water formation, and consists of sandstones, clays, and shales with the characteristic shell *Corbula perundata*; species of *Unio*, *Ostrea*, *Mytilus*, *Physa*, and *Viviparus* also occur. Some marine beds of shale are found intercalated in southern Alberta¹⁰⁴, and at the top of the Montana Group there is here a series of dark shales (*Bearpaw Shales*), containing many species of marine lamellibranchs, gastropods, and cephalopods, including *Baculites*, *Scaphites*, and *Platoniceras*¹⁰⁴. The whole succession upwards from the *Pierre* is seen along the course of the North Saskatchewan River below Edmonton, and in central Alberta. The transgressions and retreats of the sea during the Upper Cretaceous in the western plains were controlled by the balance between sedimentation and the settling down of the broad shallow geosynclinal basin⁶⁹⁰. The land and sea movements during late Cretaceous time in western Canada have been traced in detail by Russell⁴⁴⁷.

There is a passage from brackish-water into fresh-water conditions⁸¹⁹ at the end of the Cretaceous, and in the succeeding *Edmonton Formation*^{149 248 262 319 336} we find this transition into the purely fresh-water or

terrestrial conditions of the Tertiary. The Edmonton Formation forms the lower part of the so-called 'Laramie Series'^{250 319}, the upper part of which is separated off as the *Paskapoo Stage* in this region, and is referred^{262 319 492} to the Lower Tertiary. But in Wyoming^{91 149} there is a marked unconformity between the Upper and Lower divisions of the Laramie, that is, between the Cretaceous and Tertiary portions of the series³¹⁹. The Edmonton Formation consists of sandy clays, sands, and sandstones with coal-seams, and is largely argillaceous in northern Alberta. It spreads through Saskatchewan^{262 338} and is represented in Manitoba only by outliers. There is still considerable discussion as to the reference of certain beds of the 'Laramie Series'^{250 319 445 447} and the palæontological evidence is ambiguous²⁴³, for the floras²⁵⁰ of the late Cretaceous and early Eocene show no marked differences, the change being one of species and not of genera or families. But the presence of dinosaurs is held to mark a Cretaceous age, and the * *Ceratops* beds⁵²¹ (which have been variously placed) are now generally considered to be Mesozoic and not Tertiary, on account of the Mesozoic character of the vertebrate fauna, the close relations of the invertebrates²⁴³, and the stratigraphical relations of the formation⁴¹. Amongst the reptiles²⁶² the dinosaurs found in the Belly River and Edmonton beds are the most important, and a large number of genera of both the herbivorous and carnivorous groups have been obtained from the Red Deer River in Alberta. They include *Ceratops*⁵²¹, *Triceratops*, *Styracosaurus*, *Parasaurolophus*, *Kritosaurus*, and many other genera^{262 433} described by Parks⁴³⁷ and others^{483 434 443 521}. In central Alberta the Edmonton Formation has a maximum thickness of 700 ft.

(4) CORDILLERAN REGION^{814 315 318}.—The Cretaceous rocks of the Rocky Mountains are of much importance because of the coal-seams⁶²⁷ which they contain, and their wide development from the international boundary northwards into the Yukon. In western Alberta^{43 262} they are a continuation of the beds in the plains, but have suffered more or less from folding, particularly in the south-west, where they are intensely folded and faulted in the foothills^{315 613} at the base of the mountains. The lowest series is the *Kootenay Formation*, which is Lower Cretaceous⁵³⁹ in age, but by some⁵⁵¹ is held to be Upper Jurassic, as above stated. Its thickness is greatest in the mountains, and near Banff amounts to 3700 ft., but the formation thins out eastward. Its base is generally marked by a heavy bed of sandstone, and is succeeded by sandstones, shales, and many coal-seams. The whole series is of fresh-water origin, and contains plant-remains (ferns, cycads, and conifers). In British Columbia⁴⁴ the Kootenay beds have a great development with similar characters, and bear many local names. They are the chief coal-bearing series²⁷⁷, and are well exhibited in the Elk River or Crow's Nest coal-field³⁶⁷, where there are over twenty workable seams. As a rule, the nearer we approach the Rockies the more valuable the coal becomes, bituminous and steam coals replacing lignites. In the Peace River canyon^{800 623} on the 56th parallel of latitude there are important coal-seams in Lower Cretaceous beds of Kootenay age containing typical plant-remains.

On the Alberta side of the main range of the Rocky Mountains on the Crow's Nest Branch of the C.P.R.^{179 262 571 576}, the Kootenay is succeeded by about 2000 ft. of shaly sandstones, conglomerates, etc., referred to the *Dakota Formation*, and known as the *Blairmore Formation*¹⁸⁹, containing abundant angiosperms. Then follows a group of volcanic rocks consisting of trachytic flows, tuffs, and breccias, possessing peculiar alkaline characters, and reaching a thickness of over 1100 ft. These are succeeded by dark shales, which are called the *Alberta Shales*⁴⁴¹, and are of marine origin; as above mentioned, they occur also on the Interior Plains. They are divisible into a series of fossil

zones characterised chiefly by mollusca⁴⁴¹, and are equivalent to the *Benton-Niobrara*; among them are a few intercalated sandstone beds. The thickness of this marine series is from 1500-2000 ft. Light grey sandstones and arenaceous shales referable to the *Belly River Group*, with fresh-water mollusca and land plants, follow on with a thickness of 1600-3000 ft., and are the most widely distributed formation in the foothills. Some coal-seams occur in it. The *Bearpaw Shales*, with a marine fauna of Montana age^{525 526}, corresponding to the Upper Pierre farther east, succeed it, and contain ammonites in the concretions. These shales pass up into sandstones with a brackish fauna which may be Upper Cretaceous or Tertiary. Clays and sandstones, with fresh-water fossils and land plants, complete the series, and the total thickness of the beds above the Bearpaw Shales reaches in places as much as 4000 ft.; these beds correspond to the Laramie Group of Dawson. All are involved in the 'Laramide revolution' (see below). Beds of volcanic tuff are intercalated in all the Upper Cretaceous formations of Alberta from the Blairmore to the Edmonton, but no actual volcanic necks have been discovered⁵⁹¹.

The rocks in the Crow's Nest area are broken up into fault-blocks^{571 576}, with great overthrusts and downthrows to the east. The Lower Cretaceous is represented in the Bridge River area^{101 270} west of Lillooet by a series of sediments, chiefly sandstones, 15,000 ft. thick²⁷⁰, containing species of *Aucella* and *Pecten*. Associated with these beds are some contemporaneous volcanic rocks. On the British Columbia side of the Rockies in the Crow's Nest district³⁶⁷ the Upper Cretaceous is largely composed of conglomerates and sandstones with coal-seams, and the marine beds seem absent. In the south-west corner of British Columbia, near Hope in the Coquihalla area²²⁸, the Cretaceous period is supposed to be represented by patches of coarse conglomerates with subordinate shales and grits. The total thickness reaches about 8000 ft., and the rocks are frequently metamorphosed by later intrusives.

Along the Grand Trunk Pacific Railway between Prince Rupert and Telkwa, B.C., the Kootenay Formation seems to be represented by the so-called *Skeena Formation*^{207 485}, which consists of shales, conglomerates, and coal-seams⁴⁸⁵ containing the same flora. It rests conformably on the volcanics of the Hazelton Formation¹⁰⁶ and is folded in with them (Fig. 16, p. 376).

In the Coastal region^{226 369 369a} we find marine conditions largely prevailing in Cretaceous times. There is a specially important series in the Queen Charlotte Islands known as the *Queen Charlotte Series*^{44 94 418 413a}, with a total thickness of from 5000 to 9500 ft., and comprising marine sediments accumulated in shallow water, such as sandstones, shales, and conglomerates, with coal-seams in the lower portion⁵⁸. The beds rest unconformably on the Vancouver Group of Jurassic age described above, and are divisible into three formations, of which the uppermost is known as the *Skidegate Formation*. The lowest is termed the *Haida Formation*. The whole series is faulted and folded into synclinal basins and penetrated by Tertiary dykes. The fossils^{413 413a} comprise many ammonites (*Desmoceras beudanti*, *Gaudryceras sacya*, *Stephanoceras*, *Harpoceras*, *Fanninoceras*^{423 585}, etc.) and many lamellibranchs (*Inoceramus*, *Thetis*, *Trigonia*, etc.); they indicate that the beds cannot be older than the Gault of Europe⁹⁴. The Skidegate fauna belongs to the Pacific zoogeographical province of Cretaceous times, and is represented in the Utatur beds of southern India, as well as in Japan, New Zealand, and South Africa. Representatives of the Queen Charlotte Series are also found in the Thompson River Valley¹⁰⁷.

In the foot-hills of the Peace River district^{189 209 300}, and extending into the plains, there is a series of sandstones, conglomerates and shales up to 4500 ft. thick, with thin seams of lignite, which comprise Lower Cretaceous beds and

also representatives of the Colorado^{418 419} and Montana Formations. The Lower Cretaceous in part contains a marine fauna (*Desmoceras*, *Hoplites*, *Trigonia*, *Nemodon*, *Inoceramus*, etc.), and yields oil at its base. These beds are a continuation of those in the Athabasca Valley³⁴⁵, and form part of the McMurray and Clearwater Series above described. In some of the coal-bearing portion on the Pine River³⁰⁰ there are remarkable dinosaur tracks, and plant-remains (*Podozamites*, *Torreyia*, *Baiera*, etc.) have been identified from the series of sandstones, shales, conglomerates, and coal-seams which reach a thickness of some 3500 ft. in Falls Mountain. The marine beds in the series contain ammonites (*Gastrolites*⁵⁴⁰, etc.). The Upper Cretaceous portion consists partly of fresh-water and partly of marine beds, generally fossiliferous. It is known as the *Dunvegan Sandstone*, and the flora appears to be younger than that of the Blairmore Formation. The fauna⁴⁴¹ resembles faunas to the south in the United States.

On the west coast of British **Columbia** and **Vancouver Island**^{227 272} the Upper Cretaceous consists of shales, conglomerates, sandstones, and coal-seams known as the *Nanaimo Formation*^{44 123 427}, and is partly marine and partly estuarine or fresh-water in origin. It is reckoned to be 10,000 ft. in thickness, but averages in the typical area about 6700 ft., and contains many important coal-seams. The various sediments pass rather rapidly into each other both laterally and vertically, and since identical species of fossils have been collected throughout the series, it does not appear to be divisible into stages. A large number of marine forms have been described by Whiteaves⁵³⁸, and the formation may apparently be correlated with the Chico Series of Lower California and with the Pierre Formation (Montana) of the Plains^{120 123 226}. It rests on the metamorphic volcanics of the Vancouver Group, and upon the batholithic intrusions.

An Upper Cretaceous fauna of lamellibranchs from the Bearpaw Formation, with a few ammonites, has been described from south **Saskatchewan**^{420 526}, where the Cretaceous³³⁸ covers a wide area.

In the **Yukon district** the *Tantalus Conglomerate*^{247 344 450}, associated with some sandstones, shales, and coal-seams^{103 110}, measuring in all 700-1800 ft. in thickness, is now generally referred to the early Cretaceous rather than to the Upper Jurassic. The fossil flora³⁴⁴ which it contains presents no distinctive characters. The conglomerate is stated³⁴⁴ to rest conformably on the Laberge Formation in the Carmacks area, but Goranson²²⁶ claims that it underlies the Laberge, though he puts it in the Lower Cretaceous. Bostock³⁴⁴ states that the Laberge and the Tantalus Formations in the Yukon were both folded, faulted, and eroded before the extrusion of a group of volcanic rocks (*Mount Nansen Group*) of late Jurassic or early Cretaceous age, and that all were invaded by intrusive rocks probably contemporaneous with the Coast Range batholith. Volcanic activity accompanied the sedimentation, as in northern and central British Columbia²²⁶. The Upper Cretaceous has not been definitely proved to occur here.

Tectonic Movements.—At the close of the Cretaceous period occurred one of the chief mountain-building movements in North America, though the exact date is somewhat difficult to fix. It is supposed to have ended early in Eocene time. The folds produced by it trend north by west across the north-west provinces of Canada; the western limits appear to be in central British Columbia, while on the east the folds pass into the nearly horizontal strata of the plains. The gigantic overthrusts²⁶⁵ and horizontal displacements^{571 576 613} of the Selkirk, Purcell, Clarke, and Lewis Ranges in the eastern geosynclinal belt were produced at this time. There are fine examples of nappes and overthrusts²⁶⁵ dating from this orogenic period in the Crow's Nest area^{571 576} and

to the south of it⁶¹⁸. This orogenic epoch is known as the *Laramide*^{57 107}. Its effects have been traced right up through the Yukon into Alaska^{108 439}. Great volcanic activity accompanied it, but the interesting Ice River igneous complex⁹⁹ of alkaline intrusives is regarded as earlier than this Laramide revolution, though of post-Cretaceous date. Cretaceous batholithic intrusions have been recognised in the Coquihalla area²²⁸, B.C., as separable from those of Upper Jurassic age, and consist of diorite, granite, and granodiorite. As above stated, beds of volcanic ash unaccompanied by lava-flows occur interbedded in the Upper Cretaceous of Alberta⁵⁹¹. There seems to have been no widespread deformation actually on the Pacific coast itself⁴⁴⁷ at the close of the Cretaceous to correspond with these movements in the interior, for the Eocene follows on the Cretaceous farther south in the United States without a break, and no pronounced deformation took place till the close of Eocene sedimentation and vulcanicity¹²¹. There is a close structural connection⁴⁹⁶ between the Coast Range of British Columbia and the Cascade Range of Washington, U.S., to the south.

Tertiary

It is an important fact that no widespread marine deposits of Tertiary age occur anywhere in Canada. With the exception of certain local beds in Vancouver Island of Eocene age, a few of Miocene age in the Queen Charlotte Islands and the late Pleistocene marine clays near the eastern coast of the Dominion, all the formations are of fresh-water, estuarine, glacial, or volcanic origin.

No Eocene, Oligocene, Miocene, or Pliocene formations, even of fresh-water origin, occur in any of the eastern regions of Canada.

(1) INTERIOR CONTINENTAL PLAINS.

(a) Eocene

The upper part of the Laramie, which indicates continuous deposition from Mesozoic times, is known in **Alberta** as the *Paskapoo Formation*^{262 319}, and is referred to the Eocene for palaeontological reasons^{508 660}, particularly on account of the absence of dinosaurs. It is traceable from the Mackenzie River Valley in the far north of Canada down to and across the United States boundary, and has outliers far to the eastward in Manitoba. Its thickness at the outer edge of the foot-hills is 5000-6000 ft., and it contains numerous plant-remains⁴⁴⁵ and freshwater mollusca (*Unio*, *Physa*, *Limnæa*)⁴⁹², but so far none of the rich mammalian fauna of the Lower Eocene of the United States has been discovered, except for some Palæocene vertebrates in a few localities in Alberta, where mammalian bones⁶⁶⁰, including species of *Ptilodus*, *Diacodon*, *Catopsalis*, etc., have been collected, as well as some fish and reptilian remains^{572 660}. It consists of sandstones, shales, and thin lignites or coals. * The most important belt of the Paskapoo Formation overlies the Edmonton in western Alberta, and extends with an average width of from forty to sixty miles from near the international boundary to beyond the line of the Grand Trunk Pacific Railway, and doubtless . . . farther north⁹⁵. The upper part of the lignite-bearing beds (*Fort Union beds*) of southern **Saskatchewan** and central Alberta^{262 819} is assigned to this horizon. Lignite-bearing beds of early TertiaryJ age also occur in the Mackenzie Valley⁴⁹⁸ and on Peel Plateau.

An Upper Eocene vertebrate fauna has been discovered in Saskatchewan⁴¹⁶ north-east of the Cypress Hills. The fossils occur in coarse sandstone resting on a conglomerate which lies unconformably on Cretaceous beds. The affinities of the fauna are with the Uinta Formation of the United States.

(b) Oligocene

In the Cypress Hills²⁶² in Saskatchewan argillites are found containing mammalian remains (*Oreodon*, etc.)^{442 458}, like those of the White River Formation (Oligocene) of the United States, and in the Hand Hills of the prairie region in Alberta the marls, sands, and a calcareous conglomerate of quartzite pebbles are probably of about the same age. All are of fresh-water origin.

(c) Miocene

At several localities in South Saskatchewan there are deposits, chiefly gravels, termed the *Wood Mountain beds*, which contain vertebrate remains indicating their Miocene age, and are therefore younger than those of the Cypress Hills.

(d) Pliocene

It is possible that some of the pre-glacial gravels of the Interior Continental Plain may be of Pliocene age (see below).

(1A) ARCTIC REGIONS

The so-called Miocene plant-bearing beds of Grinnell Land described by Heer are now regarded as not later than Eocene, but Miocene lignites and clays with plant-remains and associated with eruptive rocks have been observed in Ellesmereland^{167 612 616}.

(2) CORDILLERAN REGION.

(a) Eocene

The Paskapoo Formation of the plains is found developed in western **Alberta** with the same characters. But the deposits of this period in most parts of **British Columbia** are local and of volcanic or fresh-water origin. Near the coast the so-called *Puget Group* may be regarded as corresponding in part with the Laramie Group. It rests unconformably on the Cretaceous, and has a great thickness in Puget Sound. Near the city of Vancouver it is over 3000 ft. thick. It consists of sandstones, conglomerates, shales, and thin coal-seams. It yields a rich flora resembling that of the Laramie on the whole. In the lower beds *Ficus*, *Aralia*, *Eucalyptus*, *Sabal*, *Cladophlebis*, and an abundance of ferns occur, while *Ehamnus*, *Populus*, and *Laurus* are found all through it. These beds are of considerable thickness in the Fraser River Delta^{208 452}. The oldest beds are of Eocene age, as above mentioned, and contain most of the plant-remains; the youngest are probably of Pliocene age, and are overlain by the Pleistocene and Recent deposits. All the beds are of fluviatile character. The Eocene beds are pierced by basic igneous rocks in the form of dykes and sills^{445 617 665}.

Certain conglomerates (*Sophie Mountain*) with poor plant-remains occur in the Rossland and adjoining district, and may be of Eocene age. They reach a thickness in places of 1000 ft., and are cut by dykes of monzonite and pulaskite¹⁸⁶.

In **Vancouver Island**^{38 227 577} in Upper Eocene or Oligocene times there was a great outpouring of lavas, chiefly basalts. These are known as the *Metchosin Volcanic Series*, and include many lava-flows, agglomerates, and tuffs. They are all basic, and the tuffs occasionally contain fossils, chiefly Eocene gastropods, indicating that they accumulated under marine conditions. These volcanic rocks are especially developed in the southern part of the island⁹², and in places are extensively sheared, faulted, and more or less altered. Dykes of diabase and masses of later gabbro penetrate them; probably these are of the same age as those in the Fraser Delta.

In the **Yukon district**^{54 344} Eocene lignite-bearing beds (the *Kenai beds*) occur in places, and are occasionally associated with diabases and andesitic and rhyolitic volcanics. These Eocene sediments were laid down in separate basins of deposition, and the lignites occur at various horizons. They are mostly but little disturbed, though locally they have suffered considerable deformation⁵⁷ by Middle or late Miocene crustal movements.

The whole region, including Vancouver Island, was subsequently subjected to extensive planation¹⁰³. The effect of these folding and erosive processes is conspicuous in Vancouver Island, Central Washington, Oregon, and California, and locally it was very intense; but in Puget Sound sedimentation seems to have gone on continuously from Eocene times, though in the southern part of Vancouver Island the Metchosin volcanics as well as the Nanaimo Series were folded by these crustal movements¹²⁰.

(b and c) Oligocene and Miocene

An enormous development of volcanic activity took place throughout **British Columbia** in Oligocene and Miocene times.

In the southern part of the province there is a thick succession of these rocks in the Tulameen district⁴⁴, divisible into two groups both referred to the Oligocene. The lower is composed chiefly of andesitic lava-flows. The upper consists of sandstones, shales, conglomerates, and coal-seams, and is known as the *Coldwater Group*; it has a thickness of about 2500 ft. Pink granite of Miocene age is intrusive into these rocks. In the Rossland area¹⁸⁶ granite porphyry pierces the intrusive boss of pulaskite of Miocene age, and lamprophyre dykes cutting all the other rocks are particularly abundant.

In the Franklin mining area in the Similkameen division of the Yale district the Coldwater Group is possibly represented by the Kettle River Formation consisting of arkoses, grits, and coarse conglomerates with intercalated flows of rhyolite and tuffs¹²⁴. This formation is succeeded after a period of disturbance and erosion by alkaline lavas and tuffs accompanied by alkaline intrusives, and these are referred to the Miocene. It is probable that the basalt and rhyolite flows with tuffs and breccias in the Coquihalla area²²⁸, associated with an intrusive diorite, belong also to this period, for they rest unconformably on the Cretaceous batholiths above mentioned.

In the Kamloops district on the Thompson River the Coldwater Group¹⁰⁷ is succeeded unconformably by the *Kamloops Volcanic Group*¹⁰¹ (including the fossiliferous Tranquille Tuffs at the base³⁸), over 4000 ft. thick⁵². It consists chiefly of basalts, agglomerates, and tuffs, with fresh-water sediments in the lower 1000 ft. containing plant- and fish-remains, and is referred to Upper Oligocene or Lower Miocene¹⁰⁸.

In the Selkirk-West Kootenay region there is an earlier (Oligocene) series of volcanic rocks as well as a later (Miocene) group.

In the Phoenix Boundary district¹¹³ Oligocene conglomerates, sandstones, and shales occur with interbedded tuffs and thin lignites, and are overlain by lava-flows of augite-trachytes, which are pierced by dykes and sills of augite-porphyrity and pulaskite.

Small basins of coal-bearing Oligocene or Miocene beds are found in many other parts of British Columbia, and volcanic rocks cover much of the interior plateaus. Many intrusive masses (batholiths and chonoliths) and dykes of a great variety of petrographical types in addition to volcanic rocks mark the Oligocene and Miocene period in regions along the 49° parallel¹¹³, and are specially developed west of the Selkirk Range³.

In the **Queen Charlotte Islands**⁹⁴ lavas (dacites, andesites, and basalts), with pyroclastic rocks, are associated with marine, estuarine, and fresh-water deposits, which are probably of Miocene age. There are also lignites in the series, and some of the beds contain marine fossils.

In **Vancouver Island**^{92 227} a group of sandstones and conglomerates containing rolled pebbles of the earlier Metchosin volcanics and gabbro as well as fossils is referred to the Miocene⁹³. These deposits accumulated as a coastal plain during the erosion cycle which was initiated in the Lower Oligocene (post-Metchosin) deformation, and reach a thickness of several hundred feet. Some plant-remains⁶⁴¹ are thought to indicate an Upper Oligocene age for part of the series. The deposits are termed the *Sooke Formation*^{5*6}, which has yielded a considerable marine fauna on the south-west coast of Vancouver Island; the marine fossils include *Aturia angustata* and many lamellibranchs, and are held to indicate a Lower Miocene age. The beds were uplifted and dissected in a later pre-glacial cycle.

In the **Yukon district** vulcanicity was conspicuous during the Miocene, though the precise horizon of some of the beds is unsettled. On the Upper White River post-Eocene volcanic rocks are extensively developed, and consist of andesites, diabase, and basalts, with beds of ash and breccia. Later Tertiary rhyolitic rocks cut through them. In the **Carmacks district**³⁴⁴, Yukon, the Tertiary clastic beds, consisting of conglomerates with andesitic tuffs and shales, some containing fragments of plants, are associated with part of the so-called '*Cannacks Volcanics*'^{344 542 577}, comprising mainly andesitic lavas, but also dacites, trachytes, and rhyolites, which rest conformably on the Tertiary elastics and may be partly Miocene in age. There are also in many parts of the Yukon intrusive acid rocks (granites, porphyry, and granophyre) which are younger than the Mesozoic intrusive granites, and are considered to be late Tertiary^{247 271}, though their precise age is doubtful.

In the **Arctic Islands**¹⁷² the fresh-water deposits containing plant-remains on Prince Patrick Island and on Banks Land, which Heer attributed to the Miocene, may be of Eocene age, like those of Grinnell Land and Greenland. Beds of lignite and thick sandy and argillaceous deposits occur along the west coast of Ellesmere Island.

Tectonic Movements.—In middle or late Miocene times there was an important epoch of diastrophism affecting the Pacific coast from Puget Sound to southern California⁵⁷. It was locally marked by folding-movements, but chiefly by faulting; it is probable that a considerable elevation of the whole region so as to form a high mass of land took place before the close of the Miocene.

(d) Pliocene

The Pliocene was a period of land-erosion. The Cordilleran region formed a land-area with much the same boundaries as at the present day. Many of the conglomerates and gravels overlying the Oligo-Miocene rocks, and probably some of the fresh-water deposits in the south of British Columbia, accumulated at this time. It is possible that some of the 'placer' deposits of the Klondike⁵⁴, particularly the high-level quartz-drift, are also of Pliocene age. Beyond the limits of glaciation the separation of the Pliocene from the Pleistocene deposits is difficult in these parts.

Pleistocene

The Pleistocene deposits of the whole of the eastern part of Canada may be divided into two main groups: (1) deposits of glacial origin⁴⁵¹ and (2) the

Champlain (marine) deposits. But the glacial period may be most conveniently treated for the whole of Canada.

(1) GLACIAL PERIOD^{382 479 507}.—There seem to have been three main centres of glaciation⁴⁵¹, known as the *Labradorean*, situated in Labrador, the *Keewatin*, lying north-west of Hudson Bay, and the *Cordilleran* in the mountain region of the west. From these three centres ice-sheets spread out, and occasionally became confluent, covering in all some four million square miles of North America, and extending into the United States to about lat. 38°, i.e. 12° farther south than in Europe. The three ice-sheets were formed in succession from west to east, but all three existed together at the period of maximum glaciation⁴⁵¹. The *Cordilleran* ice-sheet was the last to go. Local ice-sheets of less importance existed in Newfoundland²²⁵, in New Brunswick, and Nova Scotia¹⁴⁵ at various stages in the glacial period. But it is believed that part of western Newfoundland was crossed by the *Labradorean* sheet⁶⁵⁴, though this was not the case for the whole island.

Vancouver Island, like New Brunswick and Newfoundland²²⁵, had a small independent but thick ice-cap³⁸, and shows an older till, an interglacial deposit, and a later (the *Vashon*) drift^{120 123 227}.

All of Canada east of the Rockies, except the northern part of eastern Labrador and the Klondike region, appears to have been covered by ice, but perhaps not simultaneously. It seems that in Canada the *Cordilleran* ice-sheet reached its maximum before the *Keewatin*, and the latter before the *Labradorean*, though these two combined at one time so that the area of maximum ice-accumulation in North America shifted from west to east, whereas in Europe it moved from east to west. But according to Tyrrell the earliest Canadian glacier had its gathering-ground in the *Patricia* district^{38 2a}, south of Hudson Bay.

Two main glaciations separated by an interglacial period are believed to be distinguishable in North America, but there were many oscillations of the ice-sheets, which some geologists⁴⁷⁹ regard as indicating four or five interglacial periods. The three earlier till-sheets known in the United States (but not definitely recognised in Canada, except in Saskatchewan⁴⁴⁹) came from the *Keewatin* and *Labradorean* centres, and were deposited in succession. These older drifts (as in Europe) spread much farther than the newer, and while moraines, drumlins⁶¹⁰, eskers⁴⁴⁸, and other features of glacial topography abound on the newer sheets, they are almost, if not entirely, wanting on the outer area covered only by the older drift, which is characterised by a subdued topography, a monotonous uniformity in surface-features and a relatively advanced state of erosion³¹³.

The newer (*Wisconsin*) drift, which occupies a large area in Canada and extends into the northern parts of the United States, shows strong surface features, with much water-sorted material and many terminal moraines marking stages in the retreat of the ice. An earlier and a later stage are distinctly recognised. The moraines in southern Ontario, which have a considerable development^{647 648}, belong to this late stage in the glacial period. The great Kettle moraine in the United States marks the southern limit of the *Wisconsin* drift, and forms the boundary between what are known as the intra-morainic and extra-morainic drifts.

Below the *Wisconsin* or newer drift there are interglacial deposits marking a milder interval between the two main glaciations. One of these deposits in eastern Canada is known as the *Toronto Formation*^{51 563}, and consists of nearly 200 ft. of fossiliferous silts and clays lying on the older boulder-clay, and overlain by the newer drift. The beds are considered to have been

formed by a river flowing south from the Georgian Bay region into an interglacial Lake Ontario⁴⁵¹. The flora indicates a latitude 4° or 5° south of Toronto, and amongst the mollusca are species found now living in the Mississippi, but not in Ontario. In the stratified clays insect-remains are found, of which nearly all the species are extinct. Remains of elephants and other mammals also occur in this formation. Similar interglacial beds on the Moose River, near the south end of James Bay, with a thickness in places of 70 ft., have been found containing tree-trunks 18 in. in diameter. In parts of Manitoba and Alberta there are also interglacial beds containing plant-remains, and probably of the same age. The Toronto Formation seems to be of the same age as the interglacial beds in northern Illinois.

In south-western Alberta¹⁷⁹, where the glacial deposits have been studied, and their correlation with the better-known deposits of the United States has been attempted, the apparent order in which they were laid down is as follows, according to our present knowledge :—

1. Pre-Wisconsin drift of Rocky Mountain glaciers, mainly quartzite gravels (=Saskatchewan gravels in part).
2. Interglacial gravels derived from 1 (—Saskatchewan gravels in part).
3. Pre-Wisconsin boulder-clay of the Keewatin glacier.
4. Interglacial stratified beds, sand, clay, and lignite.
5. Wisconsin Stage. Drift of the mountain glaciers (coarse gravels and boulder-clay).
6. Wisconsin Stage. Boulder-clay of the Keewatin glacier, with stratified sands, etc., deposited in glacial lakes produced by damming of the mountain streams by the Keewatin glacier.

The Labradorean and Keewatin sheets were more or less confluent at the time of maximum glaciation⁴⁶, and formed the so-called ' Laurentide ice-sheet' of Spencer, which probably had several centres of dispersion, and flowed outwards in all directions to a distance of about 1600 miles from its main centre. The Labrador sheet crossed the St. Lawrence estuary, dividing into two lobes at the western end of the Gaspé Peninsula⁴¹⁰. According to Shepard²⁸⁰ the submarine trough of the St. Lawrence (Cabot Strait) was formed by ice-erosion and is a typical instance of glacial excavation. The Bay of Fundy had a similar origin^{594 606}.

The Keewatin sheet flowed west as far as the Great Slave and Bear Lakes¹⁷⁸, and almost to the foot of the Rocky Mountains, and northward across the Arctic Islands, while southwards it advanced into Kansas and Missouri. A remarkable feature is the lowness of the centre from which this sheet radiated. The glaciology of Ellesmere Land has been described by Bentham⁶¹² and others⁶¹⁶.

The Cordilleran³⁸² ice-sheet drained eastward by many large valley-glaciers, which often became confluent as Piedmont sheets on the plains of Alberta¹⁷⁹, but did not form any great lobes. This ice-sheet spread over the whole of British Columbia and southward a short distance into the United States, while northward it extended into the southern part of the Yukon. The glaciation of the Coast Range was extensive⁵⁰³. In central British Columbia one or more local ice-sheets⁵⁰⁴ appear to have operated, scouring out and over-deepening the lake basins as the ice moved southwards. In south-western British Columbia four phases of glaciation have been recognised⁶⁶¹. Interglacial beds have been discovered near Vancouver containing plant-remains which indicate mild conditions, and in south-eastern British Columbia there are similar proofs of a warmer climate. In the Cariboo and Cassiar districts the Pleistocene deposits are chiefly gravels and sands, often auriferous⁵⁰⁴. Similarly the western slope of the Coast Range bore heavy glaciers forming

thick and broad Piedmont sheets filling Puget Sound, the Strait of Georgia, and Queen Charlotte Sound⁵⁰³. The main centre of this Cordilleran ice-cap was situated to the west of the Rocky Mountains, and between lat. 54° and 59° in the interior, and the ice moved northwards as well as southwards^{382 451 494}. In the Okanagan Valley the ice-sheet was at least 6000 ft. thick. During the retreat of the ice a series of glacial lakes⁶⁶⁶ were formed in the valleys trending southwards in south central British Columbia.

According to Tyrrell⁴⁷, the above-mentioned *Saskatchewan Gravels*^{105 262 338 369} which are spread also over much of the plains of Alberta, were deposited in front of the Cordilleran ice-sheet, which laid down the Albertan till, the earliest till recognised in western Canada. This Lower boulder-clay rests on the earlier Saskatchewan Gravels, which Calhoun thinks are old river-gravels and pre-glacial in age. The gravels consist of quartzite-shingle derived from the Rocky Mountains, and are in places clayey or pass into sands and silts^{104 105}. Part of the Saskatchewan Gravels may, however, be interglacial and derived by erosion from pre-Wisconsin drift¹⁷⁹.

Then the Keewatin ice-sheet overspread the country and laid down its till on top of these deposits. Its terminal moraine is traceable in southern Alberta. Minor advances and retreats took place before the Keewatin sheet retired and was joined by the Labradorean. After these had united, the water formed by their melting and by the sinking of the land to the north was ponded between their fronts and the highland to the south and west, resulting in the formation of the large glacial lake which has been called Lake Agassiz⁴⁸, stretching over an area which is now partly occupied by Lakes Manitoba, Winnipeg, and Winnipegosis⁴⁵¹. The excavation of the basins of the Great Lakes now existing is considered by Shepard³⁰⁴ to be due to glacial erosion²¹⁵, though warping of the old peneplain^{259 313 561} before the advent of the ice may have played a part in their formation, and, as previously mentioned, their positions are related to the borders of the Canadian Shield at the junction of crystalline rocks and unaltered sedimentaries. As the Keewatin sheet still further retreated, the western portion of the Labradorean continued to advance and invade these areas, and obliterate many of the marks left by its predecessor. The clays, silts, and eskers of Lake Agassiz were formed by the materials discharged into it from the fronts of the two glaciers. At its highest stage the lake extended as far as Lake Traverse in Minnesota, and its depth at Winnipeg was about 560 feet. The final draining of the lake resulted from the retreat of the ice-sheets. Farther north, in the Mackenzie River basin²²⁰, great lakes were formed in front of the retreating Keewatin ice-sheet, and Lake Athabasca³⁴⁵ and Great Slave Lake^{365 376} are now their present diminished representatives²²⁰. North of the Great Slave Lake⁴⁴⁸ there is a remarkable development of eskers which were formed during one of the later stages in the retreat of the ice.

The downward warping²⁵⁹ of the northern parts of central and eastern Canada, which changed the slope of the land and the direction of flow of the rivers, seems to have begun just before or during the glacial period; on the retreat of the ice it led to the development of this and other great lakes along their fronts and between their lobes. Lake Agassiz^{48 220 449 615} is estimated to have covered 110,000 sq. miles, that is, the greater part of Manitoba and eastern Saskatchewan, as well as a large area to the south. In south Saskatchewan there was one large lake formed which has been termed Lake Regina^{422 449}, together with other smaller lakes⁴⁴⁹. Another such lake, termed Lake Warren⁴⁹, was the partial predecessor of the present chain of the Great Lakes, Superior, Huron, Erie, Michigan, and Ontario, which have had a very complex history. In later glacial times the so-called Lake Algonquin²¹⁵ occupied the basins of Lakes Superior, Michigan, and Huron, and covered an

area of 100,000 sq. miles. Lake Iroquois^{234 555} marks a stage in the Ontario basin, and the shore-line is still a distinct feature in the neighbourhood of Toronto. By means of the varved glacial clays of Ontario it has been estimated^{214 683} that 13,500 years approximately have elapsed since the ice retreated from the Mattawa region north-east of Georgian Bay. The sinking of the level of the water by stages as these lakes drained away over various passes and cols led to the formation of successive shore-lines, of which thirty-one have been counted around Lake Agassiz. Some of these beaches at heights of 875-985 ft. above sea-level contain species of fresh-water shells now living in the district. The last of the large post-glacial lakes was Lake Ojibway, which occupied the area forming now the clay-belt of northern Ontario and northern Quebec²¹⁵.

After the final retreat of the ice²¹⁴ the whole region was subjected to slow and probably discontinuous differential uplift⁵⁶¹, which was greatest in the north and gradually died away southwards. The tilting of the shore-lines of the glacially-dammed lakes is evidence of this uplift, which seems to have gone on intermittently^{259 304}.

(2) CHAMPLAIN PERIOD^{512 518}.—After the Great Lakes had passed through all but the last stage, there was a submergence of much of eastern Canada³³¹, so that a long arm of the sea extended up the St. Lawrence and Ottawa Valleys and the *Champlain Series* was deposited^{212 214}. Marine shells are found up to a height of 475 ft., but the submergence was much greater, and reached to about 700 ft. a few miles north of Ottawa. The sea-bottom deposits formed during this submergence consist of fine sand, silt, and clay in the Ottawa area, while the shallower water and beach deposits which mark the shore-lines consist of sand and gravel⁵⁰. The disappearance of certain marine shells and the dwarfing of others as we trace the deposits southwards are thought to indicate a progressive freshening of the water and a decrease of marine conditions²¹² in this direction.

The Champlain clays are known as the *Leda Clays* from the abundance of the characteristic shell *Leda glacialis* (= *Portlandia arctica* Gray), and have a maximum thickness of nearly 200 ft. The sands usually overlie the clays, and vary from a few inches to 40 ft., but are generally thin; they contain *Saxicava rugosa* Linn., and hence are called the *Saxicava Sands*. Other shells and plant-remains occur in calcareous concretions in the beds. The Pleistocene and Recent deposits in the Island of Montreal⁵¹² and around Ottawa⁵¹³ comprise the Boulder Clays, Leda or Champlain Clay with marine shells, *Saxicava* Sand, and gravels (beach deposits) or Champlain Sands, all also of marine origin. There are at the same time fluvio-glacial sands and gravels formed either before or after the boulder clay in the Ottawa area. In western Canada the post-glacial deposits have yielded many fossil fresh-water mollusca, mostly of living species, in Manitoba and Saskatchewan⁶⁸⁰.

The period of elevation which followed this marine submergence of the Champlain period was followed by a warping of the surface and the above-mentioned tilting of the beaches; this movement seems to be still in progress and to tend to bring back the pre-glacial slope of the land. The elevated post-glacial shore-lines of the Gulf of the St. Lawrence, Hudson's Bay, James Bay, Ungava Bay, and the Labrador coast are evidence of the intermittent upward movement which has taken place. In Anticosti Island there is a most remarkable and conspicuous succession of Raised beaches and terraces of post-glacial age. Over twenty have been distinguished, some over a mile wide and the highest at 442 ft. above sea-level²¹⁷; on the Labrador coast⁴⁸⁹ there are similar terraces and Raised beaches⁶⁰⁴ up to a height of 430 ft. Post-glacial warping has likewise affected Newfoundland⁵⁵⁴, and we may note that

the warping and deformation of the Pre-Cambrian peneplain is especially marked in the area north of the St. Lawrence⁵⁶¹.

In some parts of the **Pacific Coast** there is evidence of some post-glacial depression, as in the Skeena Valley⁵³, accompanied by an invasion of the sea and by the deposition of estuarine sands and gravels. But at the south end of Vancouver Island²²⁷ Raised beaches up to a height of 180 ft., and similar beaches on Texada Island at a height of 424 ft. above sea-level, point to recent uplifts.

The **Klondike district**^{54 619}, which did not suffer any glaciation, has its surface-rocks deeply weathered and strewn with superficial deposits. The various gravel-terraces which occur in the valleys frequently contain bones of extinct or existing northern mammals, such as mammoth, mastodon, buffalo, musk ox, etc., as well as vegetable-remains. These gravels are local in origin and frequently auriferous. Some of these auriferous gravels²⁴⁷ are of glacial, interglacial, or post-glacial age³⁴⁴, but others are pre-glacial, as is also the case in the Cariboo district, B.C.^{246 494 504}.

In **Eastern Canada** on the north shores of Lake Erie remains of the mammoth and mastodon also have been found in late Pleistocene deposits.

Igneous Rocks.—In the *Cordilleran Region*⁵¹⁷ igneous activity persisted in the western belt till Pleistocene or Recent times, and the formation of the great cone of Mount Baker, south of the C.P.R. at Mission Junction is one of these late volcanic phenomena. North of Howe Sound, Mount Garibaldi, about 8,700 ft. above sea-level, and Red Mountain⁵⁶ in the Coast Range of British Columbia, poured out andesitic lavas and ashes from early Pleistocene to Recent times¹⁹². Post-glacial⁵²⁸ volcanic rocks (lavas and tuffs) occur also in the neighbourhood of Milbank Sound^{192 577} about 160 miles south of Prince Rupert. Volcanic cones, plugs, and lava-flows with tuffs are widely scattered over the islands and along the coast. The lavas are basic andesites and basalts and some are glassy. The tuffs often contain large quartz-diorite boulders derived from the Coast Range batholith. On the islands between Burke and Douglas Channels^{859 359a} such post-glacial vulcanicity is specially evident, and on the mainland in the Skeena River there is a lake, Kitsumgallum, formed in large part by the damming of the Tseaux River by a recent lava-flow associated with several cinder and scoria cones²⁰⁷. Besides these Recent volcanoes and volcanic rocks the large number of dykes of late geological age in the coastal region of British Columbia are probably related to these eruptions. Farther north, in the Yukon and Alaska, there was considerable volcanic activity after Miocene times, continuing to the present day. For the Miocene or earlier Tertiary Carmacks Volcanic Series is followed in that district^{344 577} by a much later series of horizontal lava-flows of basalt and pillow-lavas which conform to the present surface features and must be regarded as of Recent origin. These are known as the *Selkirk Volcanics*, and rest on undisturbed gravels near Selkirk. The basic volcanics of Miles Canyon, in the Whitehorse district²⁴⁷, may be correlated with them. In the southern part of British Columbia the Tuya lavas³⁸¹ and black cinder-cones of the Cassiar district, rising to a height of 6000 ft. in some cases, are of late Pleistocene or Recent age, and there is a thin bed of volcanic ash of late origin covering hundreds of square miles¹⁰³ in the Upper White River region.

ECONOMIC GEOLOGY

Nearly every mineral of importance is found and worked in Canada and Newfoundland⁵³⁰, but only some of the principal ones

are here mentioned⁷¹¹⁹⁵, with their chief places of occurrence. In the Appalachian and Acadian region the chief metallogenetic epoch²⁹² coincided with the main period of folding and igneous intrusion in mid-Devonian times when masses of granite with dykes of syenite and porphyry were intruded, but there was an earlier intrusion of peridotites in the late Ordovician which was responsible for the deposits of asbestos and chromite. In the St. Lawrence region the galena veins which cut the Ordovician in eastern Ontario may be connected with the intrusion of the Essexites which occur in the Monteregian Hills. In the case of the Canadian Shield one of the great metallogenetic epochs occurred in the orogenic period of the Pre-Cambrian marked by the intrusion of the Algonian batholiths of granite. During this epoch most of the gold-ores and the copper-zinc sulphide replacement ores of northern Quebec and northern Manitoba were formed in relation to these intrusions. A later but also Pre-Cambrian metallogenetic epoch occurred when acid as well as basic intrusions, such as the Killarney granite and the Sudbury norite complex, were intruded into the Huronian and Keweenaw Series. The silver ores of Cobalt and the nickel-copper ores of Sudbury were formed at that time. The only later epoch of mineralisation affecting the Canadian Shield was post-Ordovician when the galena-calcite veins of eastern Ontario were developed. Thus on the Canadian Shield¹⁹⁵, where the majority and greatest variety of minerals are found, we may note in most cases a genetic connection with the irruptive rocks^{297 298} 301-303 581.

In western Canada and the Pacific region the mineralisation of the rocks belonged to a much later period, and the chief metallogenetic epochs were post-Jurassic. The distribution of the two main mineral belts in British Columbia^{190 195 296} shows a certain parallelism; there is the Pacific, or Coastal, belt on the west side and the Interior belt on the east, these belts being separated by the complex Coastal Range batholith embracing periods from Triassic to Cretaceous or even Tertiary. The ore-deposits in the Pacific belt which are chiefly worked are copper, while those of the Interior belt chiefly contain gold, silver, and lead. These belts of mineralisation run in a north-westerly direction parallel to the coast in the northern part of the Province, but near Vancouver they turn eastward and merge in the area near Kootenay Lake. The mineral veins in British Columbia may either run parallel to the bedding planes of the sedimentary rocks, or trend in two main directions north-west and north-east, thus apparently being related to the major fractures of the fiord-system. In general the ore-deposits of British Columbia are of primary origin³⁶², but the native silver in the Salmon River²⁰⁸ and Alice Dam districts suggest secondary enrichment. A large variety of rock types contain valuable ore-shoots, but nearly all

were formed from solutions derived from the grano-diorite intrusions of Jurassic age. There are, however, a few connected with Pre-Cambrian intrusions (*e.g.* in east Kootenay), and some with Tertiary eruptions such as at Sunloch on Vancouver Island, where copper occurs in Tertiary gabbro; the mercury occurrences in various localities in British Columbia are likewise of Tertiary origin. Some of the mineral deposits were produced by mechanical or chemical action and processes of concentration. Such are the pre-glacial or Pleistocene or post-glacial and Recent auriferous gravels of the Cariboo^{246 341 516 593 599a 642} Fraser, and other areas. "

Apatite (see ' Phosphates,' p. 364).

Arsenic.—Arsenic-bearing minerals⁴⁶⁵ are of many kinds (copper, iron, silver, etc.), occurring in connection with igneous intrusions in Canada. On the Canadian Shield the most important area is between Lake Huron and Lake Abitibi, especially in the Cobalt district. In the Cordilleran region the arsenic-bearing minerals occur mostly along the east side of the Coast Range and in south-central British Columbia. In the Acadian region they are found in various places in New Brunswick, Nova Scotia, and eastern Quebec.

Asbestos^{59 60 195 283 467} is the chief mining product of Quebec, and is of the chrysotile variety. It occurs in veins in the post-Ordovician serpentines, which occupy a belt of three more or less distinctly separated areas, extending from the Gaspé Peninsula southwest across the eastern provinces of Quebec into Vermont. The middle area, about 23 miles in length, is the richest, and includes Thetford²⁸³ and Black Lake. The serpentines lie between Ordovician sediments on the east and slates and schists of Cambrian or Pre-Cambrian age on the west, and belong to the so-called Thetford Series of post-Ordovician intrusives, ranging from dunites to aplites and resulting from the differentiation of a laccolite after its intrusion. In the serpentine belts in Newfoundland asbestos also is found.

Barytes^{65 195}.—In north-eastern Nova Scotia barytes is widely distributed in Pre-Cambrian or Palaeozoic strata in irregular pockets, veins, or bodies, especially in the Lake Ainslie district³³⁷. The barytes veins in Cape Breton carry also calcite and fluorite, and cut across or run parallel to the enclosing Pre-Cambrian schists. Some of the veins are 20 ft. wide. At one place on the Bay of Fundy the mineral occurs in fissures, fault-zones, and fault-breccias in sharply-folded Devonian slates and quartzites, associated with various other minerals.

Coal^{43 44 58 195 627}.—The ages of the chief coal-deposits in Canada are Carboniferous, Cretaceous, and Tertiary, and the

principal coal-fields are on the Atlantic and Pacific coasts, especially in Alberta, and in the western foot-hills and the interior of British Columbia.

Upper Devonian or Lower Carboniferous.—Cannel and oil-shales of the Arctic islands.

Upper Carboniferous:—

(1) 'Millstone Grit' (Pennsylvanian) of New Brunswick^{268 290} containing only thin seams of coal.

(2) Coal Measures proper (Windsor Series) of Nova Scotia and New Brunswick^{223 238 257 268 274 290}, exposed in the Cumberland, Pictou, Inverness, Cape Breton, and Sydney^{274 463} areas. These are the most important coal-fields of Canada.

(3) Coal Measures of Newfoundland, on south side of St. George Bay, and in Humber River Valley.

Lower Cretaceous (or Upper Jurassic)^{195 277}.—Bituminous coals and anthracite of the Rocky Mountains and foot-hills, Alberta^{262 306 314 315 335 645} and of many areas in the interior of British Columbia^{367 485} and Yukon; also in Queen Charlotte Islands (Skidegate Formation). Chief coal-fields (in Kootenay Formation) Crow's Nest Pass³⁶⁷, Elk River in Rocky Mountains; Yukon (Tantalus area) and Whitehorse basin²⁴⁷. The Kootenay coal measures extend up to the north-west of Lake Athabasca and into the Peace River⁶²³ district.

Middle and Upper Cretaceous.—Alberta, Saskatchewan^{262 338} (Lethbridge coal-field in Belly River Formation; Edmonton district in Edmonton Formation²⁶²). Peace River⁶²³, Vancouver Island^{227 272} (Nanaimo and Comox coal-fields).

Tertiary.—Mostly lignites and sub-bituminous coals of small value. In Alberta and Saskatchewan^{262 338} in Paskapoo Formation. Many small basins in British Columbia and Yukon²⁴⁷, of Eocene, Oligocene, and Miocene age.

Corundum^{64 195}.—The occurrences of corundum in Ontario are unrivalled because of the size of the areas covered by the rocks which yield the mineral and its richness and unaltered character. The corundum-bearing rocks occur in three distinct bands, the longest of which extends from north-east to south-west for about 103 miles, with a maximum width of 6 miles. The mines are situated in the eastern part of the province in the townships of Carlow and Raglan. The rocks are various types of alkali syenites, nepheline-syenites, etc., but show a rapid and extreme variation in composition and range to essexites and more basic types, and also to rocks analogous to anorthosites¹⁹⁵. But as a rule ferromagnesian minerals are scarce, and quartz is usually absent, while

scapolite or nepheline may wholly or partly take the place of felspar. The rocks in most cases lie along the margins of the granite batholiths where in contact with crystalline limestone. They form part of the Pre-Cambrian complex of the 'Canadian Shield,' and are regarded as a peripheral phase of the granite-gneiss intrusions into the Grenville Series. The corundum is a primary constituent of the rocks, but the amount of it varies considerably. Crystals of all sizes up to 60 lb. in weight are found.

Fluor-spar.—In Newfoundland⁶³⁰ on the southern part of the Burin Peninsula fluor-spar is found filling fissures mainly in the granite intrusive into Pre-Cambrian and Cambrian sedimentaries⁵³⁰, but also in the associated dykes and sills of rhyolite, porphyry, and lamprophyre. The veins vary from a few inches to 50 ft. in width, and are mostly nearly vertical.

Felspar¹⁹⁵.—This mineral in the form of orthoclase occurs in great purity in pegmatite veins and dykes in Quebec and Ontario, and is worked on a large scale near Kingston.

Graphite^{66 195}.—The graphite ore-bodies in Quebec and Ontario are found closely associated with intrusive dykes and sheets of diorite, pegmatite, and gabbro piercing the Laurentian gneiss and Grenville-Hastings Series. But in the Grenville Series of Louisa, Quebec⁵⁸⁶, the graphite occurs at the junction of the greywackes and limestones, and is believed to have been introduced by solution, replacing earlier silicate minerals. It also occurs there disseminated in veins of pegmatite. The mineral occurs either as bedded masses in crystalline limestone, or near the contact of the latter with igneous rocks, or as true fissure-veins cutting the gneiss and other eruptive masses, or, thirdly, as disseminated scales in gneiss, limestone, gabbro, pyroxenite, and pegmatite.

Gypsum⁶³.—Beds of gypsum are associated with the Lower Carboniferous limestones in New Brunswick¹⁴⁷, Nova Scotia, and Cape Breton³³⁷. They are very extensive and reach a thickness of 200 ft. or more. Anhydrite occurs generally with the gypsum, sometimes in alternating beds. The same gypsum beds occur in the Magdalen Islands³⁷⁸, and in Newfoundland. In south-western Ontario⁵⁶⁸ gypsum beds are worked in the Salina Formation (Silurian) associated with rock-salt, and in southern Ontario lenticular masses are found in the Onondaga Formation.

In northern Manitoba⁹⁸ gypsum is interbedded with Silurian dolomites, and south of Hudson and James Bays it occurs in the Devonian, while in British Columbia it is found on the Thompson River and elsewhere. On the Peace River and in the Slave River

country beds of gypsum of Devonian age attain a thickness of several feet¹⁷⁸.

Lithium.—A complex dyke, near Lamprey on the Winnipeg River, comprises three zones : (1) a lower chiefly of albite-granite, (2) a middle zone partly of lepidolite and other minerals, with the outer part of the zone chiefly composed of large microcline and quartz-spodumene crystals, and (3) an upper zone chiefly of quartz-muscovite rock. Lithium-bearing minerals mainly occur in the middle zone. This dyke cuts volcanics^{309 331} of uncertain age, the surrounding area consisting of basalt.

Magnesite⁶⁷.—Extensive beds, mostly lenticular, occur in Quebec associated with bands or lenses of serpentine *in* the Grenville Series of limestones and dolomites²³⁰. The elongation of the lenses and planes of banding are mostly parallel to the strike of the Grenville Beds, and the magnesite seems to have been formed by the alteration and replacement *in situ* of these limestones. In British Columbia in the Bridge River area^{270 296} magnesite occurs in the massive form as the result of the hydrothermal alteration of Mesozoic intrusive serpentine. In the Cranbrook area²⁶⁹ the magnesite deposits occur in the Purcell Series, and are said to grade into the quartzites.

Mica^{61 62 195}.—The amber-mica (phlogopite) deposits occur *in* Quebec between the Gatineau and Lievre Rivers, and in Ontario he principally in an area east of the Kingston and Pembroke Railway. The mineral is found as segregations in dykes or pockets of pyroxenites, which consist chiefly of pyroxene, calcite, apatite, and this mica. The segregations chiefly occur where the pyroxenite intrusions (which traverse Grenville and other Pre-Cambrian rocks) are themselves cut by later more acid intrusives (granites and pegmatites).

The white mica (muscovite) occurs in pegmatite dykes in Quebec (*e.g.* in Buckingham district) as isolated crystals, or in accumulations near the walls of the dykes cutting the Grenville Series, or in sheets or lenses enclosed in the gneisses.

Oil and Gas^{72 476 578}.—The chief oil- and gas-producing district in eastern Canada^{562 562a} is in the peninsula of south-western Ontario between Lakes Erie and Huron³²⁴. There are several productive horizons (Trenton, Medina, Clinton, Guelph, Salina, and Onondaga⁶⁶²), but the chief one for oil is the Onondaga. In some cases structural anticlines seem to determine the occurrence of the oil and gas. The oil-fields in Lambton County are the most important. The chief gas-fields are in Essex and Welland Counties,

and the oil and gas come chiefly from the Clinton or Guelph formations³²⁴, or in some cases from the Salina below, or the Delaware above, the Onondaga formation, and less often from the Trenton. In Quebec the most important and promising source of oil is in the Gaspé district^{323 324} where Devonian rocks are thrown into a series of anticlines. It is believed that the Gaspé Sandstone is the formation which yields the oil, but the Grande Grève Limestone may be its original source. In New Brunswick the Albert Series^{195 268 324} of Lower Carboniferous age yields petroleum and natural gas, and consists of a basal conglomerate overlain by sandstone and shale which are bituminous and grade up into rich oil-shales in the Hillsborough district. The Albert Shales in the adjoining region of Nova Scotia likewise contain oil in valuable quantities^{72 73 324}. In Newfoundland the oil is all derived from Ordovician strata, but only in small quantities.

The oil- and gas-fields in Alberta^{189 464} 576 578 622 672-674 and British Columbia⁴⁷⁶ are located in various widely-separated areas on the Great Plains and in the foot-hills 636 672 of the Rockies. The folding and faulting which characterise the foot-hills⁶⁷² die out eastward, but there is a great syncline in Central Alberta, south of the Lesser Slave Lake, with a low anticlinal to the east, both with super-imposed minor local folds. The beds concerned in these structures are chiefly Cretaceous and Tertiary.

In Alberta^{189 292} the Lower Cretaceous is the chief reservoir of oil and gas, and their occurrence seems connected with wide folds existing in the eastern part. In southern Alberta^{189 607 672} the fields mainly produce gas, as near Medicine Hat where it comes from Upper Cretaceous beds. But in the Turner Valley^{476 570 576} 622 635 657 668 673 both gas and oil are found, and both⁶⁵⁷ come from the Mississippian (Lower Carboniferous) limestones and dolomites. In the central Turner Valley⁵⁷⁰ the beds are much disturbed by over- and under-thrusts⁵⁷⁶. Soft sandstones saturated with heavy petroleum, semi-liquid maltha and asphalt, occur along the Athabasca River for a distance of over 100 miles north and south of Fort McMurray¹⁷⁸. These are the so-called '*Tar Sands*'^{178 345 385 635}, and are of Lower Cretaceous age. Two oil horizons, one in the Lower Cretaceous and the other in the Colorado, appear to be present in this area. It is believed that the oil originated in the Lower Cretaceous strata, of which the McMurray formation forms a part, but it may come from the underlying Palaeozoic limestones. In the Eastern and Western Peace River areas the Lower Cretaceous has yielded oil or gas in drill holes^{292 476}. But the Mackenzie River basin^{178 198 205 254 464 476 578 592} is one of the most important areas and is underlain by oil-bearing Palaeozoic rocks which, in the Norman Range^{464 578} on the east bank, are folded into an anticline of

Silurian and Devonian rocks, of which the oil-producing horizon belongs to the Upper Devonian.

Phosphates^{62 195 216}.—Apatite, when segregated in veins or pockets either as distinct crystals or as massive crystalline aggregates, has been worked in the pyroxenite intrusions in the Grenville Series²¹⁰ (along with phlogopite mica) in the provinces of Quebec and Ontario. Its occurrence is closely associated with dykes of more acidic character which cut the pyroxenites. Two main producing fields exist, of which the Lievre River district in Quebec, stretching north from the Ottawa River, is the more important.

Salt.—Salt-deposits occupy a large buried basin along the shores of Lake Huron. They occur in the Salina Formation, and the beds sometimes reach a thickness of 250 ft. Salt also occurs in brine springs issuing from the Devonian in Manitoba, and from the Lower Carboniferous in Nova Scotia^{267 435} and New Brunswick. The important Malagash salt deposit^{267 435} is interbedded with the Windsor Series in Nova Scotia, and appears to form a dome-like structure.

Talc²⁴⁴.—Most of the deposits in the western and central belts of the Cordilleran region are found in association with metamorphosed basic igneous rocks. In the Eastern Provinces they occur (1) in association with the Serpentine Series of the Appalachian Mountains; (2) associated with Pre-Cambrian dolomite in New Brunswick; and (3) in the pre-Carboniferous complex of Cape Breton Island and Antigonish County, Nova Scotia. In the Canadian Shield the principal deposits of high-grade talc are found in the Madoc district, Ontario, in the Grenville sub-province, where highly-metamorphosed basic and other igneous rocks occur together with beds of dolomite and other magnesian rocks; there are also zones or masses of soapstone in gabbro in the region north-west of Lake Superior.

Building and Ornamental Stones⁹⁵.—In the Maritime Provinces many of the chief building stones are furnished by the sandstones of the Carboniferous. The valuable granites are only worked in a few places.

The limestones quarried in the province of Quebec are largely obtained from the Chazy and Trenton Formations. Granites and other plutonic rocks are quarried in northern Quebec from the Pre-Cambrian and in the southern part of the Eastern Townships from intrusions of later date. The igneous rocks of the Monteregian Hills also furnish 'black granites.' Marbles of Pre-Cambrian (Grenville) age are worked in the northern part of the province, and Ordovician and Silurian metamorphosed limestones yield many types in the eastern townships.

The province of Ontario is rich in limestones of Ordovician, Silurian, and Devonian age. The Chazy, Trenton, and Niagaran Formations are the most important. The Pre-Oambrian and Archaean marbles and granites largely await development. The blue sodalite which occurs in belts of nepheline-syenite in the Haliburton district is unique.

In Manitoba, Saskatchewan, and Alberta the sandstones are almost entirely of Cretaceous or Eocene age, but the many types of limestone, ranging in age from Cambrian to Cretaceous, are only utilised in a few places.

Antimony¹⁹⁵.—In Nova Scotia auriferous stibnite and native antimony occur in association with gold and copper ores in veins in fault-planes in the Pre-Cambrian Meguma, or 'Gold-bearing,' formation. In New Brunswick veins of native antimony and stibnite occur in Palaeozoic shales and quartzites near intrusions of diabase and granite.

Chromite.—In Quebec the serpentines of the Notre Dame Hills which cut the Ordovician beds in the county of Brome furnish the chrome-iron deposits as well as the asbestos. The chromite occurs as a series of lenticular masses of ore, or is disseminated as grains through the associated serpentine. In the Eastern Townships of Quebec⁴⁶⁷ chromite occurs in the peridotites and pyroxenites.

In the Tulameen district, B.C., chromite occurs in the peridotite intrusions of post-Triassic (but probably pre-Cretaceous) age in close association with platinum (see below).

In Newfoundland⁵²⁸ chromite is found at Port au Port Bay and at Mount Cormack in connection with serpentine, as in Quebec. The serpentines, which are the north-eastward extension of the Appalachian serpentine belt, occur in two long zones, of which the western one is the best known and is parallel and adjacent to the west coast. The folded rocks into which the ultrabasic intrusions have occurred are of Ordovician age. In the eastern zone the sedimentary rocks which have been invaded are referred to the Quebec group. In both cases the serpentine belts lie parallel to the general structural trend of the island. The dunite, which is mostly serpentinised, is associated with pyroxenite and peridotite⁵¹⁹ in many cases, while the chromite is found disseminated in the rock or as compact lenses.

Cobalt^{567a}.—Cobalt occurs in the silver-cobalt nickel ores of Cobalt^{520 533 582 587 596} (see under 'Silver'), Ontario, and in the Sudbury copper-nickel deposits (see under 'Nickel').

Copper.—British Columbia¹⁹⁵ is the principal producing province. The most important localities are on the Pacific coast and in the

West Kootenay and Kamloops district. The Boundary district³³³ possesses huge deposits of low grade, occurring within a series of Palaeozoic sediments (as at Phoenix^{113 195}), which are themselves cut by small intrusions of syenite of Tertiary age, and lie near a batholith of granodiorite. The ore-bodies are of the metasomatic and contact-metamorphic type, and are mainly confined to beds of metamorphosed limestone¹¹³ and tuff, but are usually without well-defined walls. At Allenby, near Princeton¹⁹⁵, there are Palaeozoic sediments invaded by a stock of monzonite cut by veins of pegmatite and calcite; the copper ores occur either near the contact of the monzonite and Palaeozoic sediments or in zones of fracturing in both rocks filled with calcite. In the Tulameen district, B.C., ore-deposits are also generally at or near the contact of igneous rocks. The most productive deposits of copper are at the Britannia Mines on Howe Sound¹⁹⁰ on the Pacific coast, where they occur in a band of metamorphosed slates and quartzites invaded by masses of quartz-porphyry and diorite belonging to the Coast Range batholith. The mineralised band lies along a shear-zone and contains auriferous sulphides of copper. At the northern end of British Columbia in the Salmon River district²⁰⁸, and near Anyox close to the Portland Canal north of Prince Rupert, there are also important copper deposits. At Granby Bay, Observatory Inlet, the ores are massive sulphides and occur in irregular replacement shoots near the centre of a large mass of argillites and greenstones often highly altered and cut by the Coast Range batholith of granodiorite. The Texada Island^{128 195} copper deposits likewise occur at or near the contact zone of the (Trias-Jurassic) limestone with the intrusive diorite. Many copper-bearing deposits occur on the islands on the Pacific coast, especially on Vancouver Island, usually near the edge of diorite and other igneous rocks intrusive into early Mesozoic sedimentaries. But in the south of Vancouver Island¹⁹⁵ the ore occurs in volcanic rocks of Tertiary age cut by a dyke of gabbro.

In the Whitehorse Copper belt, Yukon²⁴⁷, the contact zone of the Carboniferous limestones and intrusive granite and gabbro is likewise the site of copper deposits. In the Hazelton district¹⁸⁰ chalcopyrite occurs in fissure-replacement or shear-zone replacement veins in the Hazelton Series. From most of these copper occurrences gold is also obtained (see 'Gold').

Native copper occurs in the Keweenaw diabase of Lake Superior, and also in the far north-west in amygdaloidal basalt on the Coppermine River, on Bathurst Inlet¹⁷⁸, and on Coronation Gulf.

The chief source of copper in Ontario is the nickel-copper ore^{301a} 302 of Sudbury (see 'Nickel')⁵⁶⁴.

In the neighbourhood of Sherbrooke in Quebec, the ore (chiefly chalcopyrite) occurs in or closely associated with schistose porphyries and andesites of Pre-Cambrian age. The important sulphide ore bodies of Noranda in Quebec and Flin Flon in Manitoba^{331 548 614} consist of lens-like masses of sulphides of copper and other minerals as replacements of Pre-Cambrian rocks. In the Rouyn district of Quebec^{293 328 469} similar auriferous copper ores occur in Keewatin rocks, and there is some close connection between the existing sulphide bodies and the intrusive granodiorite-quartz-diorite bodies⁴⁰⁹. Another class of copper-deposits occurs as irregular bodies in Ordovician limestones and other sediments near intrusive dykes, along a zone stretching north-east from Roxton, Quebec.

The Tilt Cove deposits in Notre Dame Bay, Newfoundland, are lenticular masses of cupriferous pyrites in the Ordovician (Luzon Formation) rocks associated with intrusive serpentine of later date⁹⁷. The ore-deposits⁶⁶² for the most part are pyritic copper-replacements in sheared and chloritised pillow-lavas⁵³⁰. Some of the intrusive diorites have also been converted into chlorite schists. There are many other deposits of copper ores in other parts of Newfoundland, and the genetic connection between the intrusions of diorite, quartz-diorite or granodiorite into chlorite-schists has been demonstrated. All the copper produced is derived from sulphide ores. At Buchans, Newfoundland^{488 510 530}, the lead-zinc-copper deposits are in the Ordovician tuffs which were mineralised after or in connection with the intrusion of quartz-porphyry following granite and diabase, all of pre-Carboniferous age.

Gold.—The gold of Canada^{293 417} is mostly produced from Pre-Cambrian rocks in the Canadian Shield, especially from Ontario^{293 455-457 565 566} Quebec³⁶³, and Manitoba⁵⁴¹. The deposits are of two main types: (1) quartz-veins, and (2) sulphide deposits. In most cases they are found in or in close proximity to intrusive igneous rocks and have genetic relations with them²⁹⁷. The second main auriferous area is in the Cordilleran region where most of the gold has been won from placer deposits, but complex sulphide ores from lodes in relation to the Coast Range batholith are now another important source of the mineral. A third region, including the Eastern Townships of Quebec³⁶³ and Nova Scotia, consists of Palaeozoic folded rocks as well as Pre-Cambrian, and the deposits occur as quartz veins which in Nova Scotia, as before mentioned, assume the unusual form of saddle reefs^{44a 176 293 327}. The auriferous sulphide ore-bodies on the Canadian Shield are chiefly mined for other minerals (mainly copper), as at the Flin Flon mine. These saddle reefs in the 'Gold-bearing series' of sedimentary rocks are in the form of interbedded quartz-veins, thickest along the domes of

the anticlinals into which the quartzites and slates have been thrown, but they are rarely found in the synclines. The veins were formed during the folding of the rocks by infilling of the openings and vacuities produced by the movements of the strata. The granite intrusions which cut through the strata and the veins are of later date. The gold occurs in the quartz veins irregularly, and is commonly associated with galena, but many other minerals also occur with it.

In eastern Ontario^{293 360 484} the auriferous veins occur in fissures in the Grenville Series, generally near the granite intrusions, or they lie parallel to the foliation of the schists as a succession of lenses. In western Quebec^{210 276 293 328 360 363} the gold deposits are found over a large area near the Ontario border in Pre-Cambrian rocks, and mostly occur in shattered or sheared zones produced by faulting, the faults falling into four or five sets with different trends. The ore-bodies have not been derived from a single intrusive, the syenite-porphyry, but from many different types of pre-Huronian intrusives, and the veins occur in granites, granodiorites, lava-flows, tuffs, and Timiskaming greywackes. In the Beauceville map area placer-deposits contain gold²¹⁹. In the Cadillac area, Quebec²⁷⁰, the gold occurs in quartz veins and in mineralised zones, and it is in association with sodic intrusives (albitite and quartz-albitite) in Pre-Cambrian rocks.

In western Ontario⁴⁸⁴ and Manitoba^{171 177 343 345}, fissure veins and segregated veins occur likewise in Pre-Cambrian rocks. In south-east Manitoba^{331 343} the gold deposits are quartz bodies along shear zones in the Pre-Cambrian. In the Lake Athabasca area³⁴⁵ the veins occur in the granite. The Porcupine area^{23 278 384 457 484 499} has most of the gold-bearing veins in the Keewatin rocks, which chiefly consist of much decomposed schists and acid and basic volcanic rocks, chiefly basalts, intruded by quartz-porphyry. The quartz-veins are regarded by some geologists as themselves the final differentiation product of the intrusive granite-magma²⁹⁷, and sometimes contain feldspar, scheelite, and tourmaline, and behave like intrusive dykes. Some are lenticular or dome-shaped masses of quartz. But nearly all the ore-bodies in this field lie in wide shear-zones⁴⁹⁹. In the Kirkland Lake area^{293 455 456} the ore consists mainly of mineralised crushed and shattered syenite-porphyry along a large earlier fault, and, as in the Porcupine area, the auriferous deposits seem to be related to the synclines of sedimentaries and to neighbouring granite batholiths. Similar structural relations are found in the Kolar goldfield in Mysore³⁸⁴. The gold deposits in the Rouyn-Harricana area³²⁸ on the east border of Ontario, which occur in the Keewatin and Timiskaming Series, are likewise arranged along major synclines. In the Hollinger Mine⁴⁵⁷

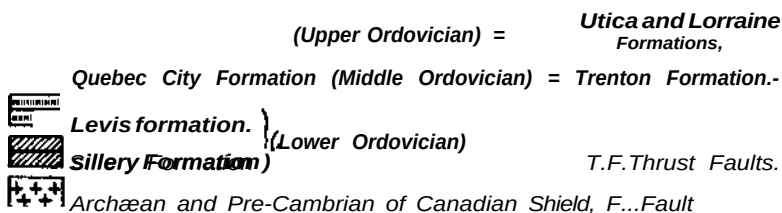
604 611 the ore-bodies occur in much-folded and altered Keewatin lavas intruded by stocks of quartz-felspar-porphyry now altered chiefly into sericite schists. The gold occurs in quartz-veins and also in the wall-rock⁶¹¹.

Tyrrell¹⁴¹ considers that most, if not all, of the gold-bearing veins in central Canada were formed in the Algonian period.

There are many auriferous²⁹³ ore-deposits in the Cordilleran region, especially in the Kootenay^{269 330} area, where the gold occurs in lodes in association with other more abundant minerals, but in the south-western part of British Columbia, the Bridge River area^{270 466 515} and several areas near the International Boundary³⁶¹ also there are some important gold mines. The ore-deposits here are in quartz-veins in Mesozoic rocks and in proximity to the Coast

Ss

M



M. Montmorency. I.O. Island of Orleans. S.J.L. St. Joseph de Levis.

FIG. 14.—GENERALISED SECTION ACROSS THE ST. LAWRENCE NEAR QUEBEC (based on Sections by Selwyn and the Geological Survey).

Range batholith. In British Columbia the gold is mostly obtained from the sulphide-ore deposits of copper, the nature of the ores being very complex^{296 515}. In Rossland, B.C.²⁹³, the ore occurs in fissure veins, or as a network of veinlets in zones of shearing, or as irregular impregnations, and always near the contact of intrusive granodiorite and monzonite or alaskite with Carboniferous sedimentaries. The ore-bodies may occur in any of the country rocks. The main ores are pyrrhotite and chalcopyrite.

In the Hedley²⁹³ mining district on the Similkameen River the limestones, quartzites, argillites, volcanic tuffs, etc., of supposed Carboniferous age, are intruded and metamorphosed by sills of diorite and masses of diorite and gabbro. The ore-deposits lie in the altered limestones as irregular and ill-defined bodies. The chief minerals are arsenopyrite, pyrrhotite, chalcopyrite, and pyrites.

In the Boundary district gold-copper ores likewise occur.

The Cariboo²⁴⁶, Atlin, and Klondike⁶¹⁹ districts contain important detrital ('placer') deposits. These deposits have been specially worked in the Cariboo²⁴⁶ 341 381 504 516 583 599 642 and Barkerville^{246 341} areas, and the gold is believed to have originated from the gold-quartz veins in the Pre-Cambrian Cariboo Series⁵⁹⁹, followed by gradual accretion from gold solutions in the gravels⁵¹⁶. In the Yukon area^{247 271 293 344} the quartz-veins which have provided the gold and the materials for the gravels are found in the pre-Devonian (? Pre-Cambrian) rocks (chiefly schists), which are penetrated by intrusive granite and diorite dykes. There are three sets of gravels: low-level, intermediate, and high-level, of which the low-level are the most important, and contain bones of existing and extinct species of northern mammals, including mammoth and mastodon, buffalo, bear, musk-ox, etc. The high-level gravels may be of Pliocene age, but yield no organic remains. On the west coast of the island of Vancouver²⁷², and on Princess Royal Island, some gold has also been mined.

Iron^{68 69 279}.—The most important source of iron at present is the Helen Mine in the Michipicoten district^{222 235 565 565a}. The rocks here belong probably to the Lower Huronian, and are very similar to those of the Vermilion Iron Range, south of Lake Superior. They consist of banded cherts, sideritic cherts, banded jasper, quartzites, various schists, and the iron ores themselves (haematite, magnetite, limonite, siderite, and pyrites). The haematite and limonite, constituting the workable ores, are believed to have been formed by a process of decomposition and leaching of the carbonate ores which have been redeposited as oxides. The iron formation lies in a closely-folded syncline in Keewatin schists^{236 237}. A similar iron-ore formation is found in the Belcher Islands, Hudson Bay^{173 575}, and in many other localities in Pre-Cambrian formations.

The Atikokan Range in western Ontario possesses a different type of ore-deposit. Three nearly vertical bands of magnetite, 40, 10, and 16 ft. wide, lie parallel to one another in a breadth of less than 250 ft. of a belt of chJoritic (Keewatin) schists. The Moose Mountain deposit, about 30 miles north of Sudbury, Ontario²³⁷, likewise consists of magnetite ores, which are usually interbanded with cherts or occur in irregular masses.

In eastern Ontario numerous deposits of magnetite occur, in many cases lying along the contact of crystalline limestone (Grenville Series), with various intrusive igneous rocks.

The Lake St. John district, Quebec, is noted for the huge segregation-masses of titaniferous magnetite *in* the anorthosite or gabbro intrusives in the Laurentian and Grenville formations⁴⁵³.

In the Nictaux-Torbrook district, Nova Scotia, the iron-ore beds of haematite occur conformably intercalated in the fossiliferous Devonian, and are of sedimentary origin. The ore occurs in two parallel zones on opposite sides of the syncline into which the beds of slate and quartzite are folded. Intrusive dykes and masses of gabbro and diorite invade the rocks, which are cut off on the south by a batholith of granite. In the Londonderry district the ores consist of limonite and carbonate in a zone of Assuring in a band of conglomerate and sandstone.

In the deposit near Bathurst, New Brunswick, the siliceous magnetite occurs as lenses in crushed quartz-porphry with their longer axes parallel to the schistosity.

In British Columbia^{195 279} contact-deposits of magnetite occur on Texada Island^{128 213}, where limestones of Triassic or Jurassic age are in contact with diorites or porphyrites, and the ore forms a series of lenses. Closely similar deposits occur on Vancouver Island and on Queen Charlotte Islands. The bulk of the ore-deposits are replacements of the igneous and calcareous rocks, metasomatism having taken place on a large scale, as in Texada Island^{128 213}. Magnetite deposits with gold-quartz veins also occur in the Carmacks area in the Yukon, in the Pre-Cambrian (Yukon Series) rocks at Fregold Mountain⁵⁴².

In Newfoundland there is the famous Wabana²⁶³ Mine on Bell Island^{69 530}, and here the iron-ore deposit is of immense extent. Broad lenticular beds of ironstone from a few inches to several feet thick form six zones, and are intercalated in unmetamorphosed Ordovician shales and sandstones lying in a syncline which occupies the whole of the bay. The ore is chiefly haematite, with some siderite and chamosite, and is mostly oolitic. Arenig and Llandeilo graptolites and brachiopods occur in the ore, and the ore-beds are regarded as primary sediments. The average percentage of metallic iron is 53 per cent., and of silica 11-14 per cent.

Lead and Zinc^{195 292}.—The fullest description of the lead-zinc deposits in Canada is given by Alcock²⁹², and reference should be made to his memoir for details. In most cases the ore-deposits are associated with silver, the galena being generally argentiferous. The most important lead- and zinc-deposits in British Columbia are in the region between the Arrow and Kootenay Lakes, especially the Slocan district^{339 340}. The veins are mostly argentiferous and occupy fissures in the Palaeozoic slates formed subsequently to the intrusion of the porphyry dykes and granites. The deposits may also take the form of replacements in limestone, forming chimney-like shoots. A third mode of occurrence is along the planes of schistosity or zones of shearing in the sedimentary beds. Near

Mozie²⁹² on the Crow's Nest branch of the C.P.R. the ore-bodies lie in two nearly vertical fissures in Cambrian quartzites, and may have a width of 30-40 ft. In most cases the ores are argentiferous galena and zinc-blende.

Argentiferous galena is found as a contact or replacement deposit in the Lardeau map area³²⁹ of the Kootenay district, and in the Windermere map area²³², and lead-silver-zinc deposits are numerous in veins in the Purcell Series (Pre-Cambrian)²⁹², and in many other places in southern British Columbia²⁹². In the Golden mining district the silver-lead-zinc deposits occur in fissures in the limestone, or as replacements of shattered limestone of Middle Cambrian age on the face of Mount Stephen^{292 312}. In the north-western part^{292 334} of British Columbia there are many deposits of lead and zinc, as in the Atlin Lake region, Portland Canal^{292 334}, as well as in the Hazelton^{180 292}, Skeena, Smithers, Finlay River⁶²⁰, and Telkwa districts. The rocks here are mostly members of the Coast Range batholith³²⁰ complex and associated intrusives near or in which the ore-deposits occur, but often the veins penetrate Pre-Cambrian, Palaeozoic or Mesozoic rocks. In the Mayo district, Yukon⁵⁶⁹, silver-lead deposits, with other minerals, occur in veins following faults traversing Pre-Cambrian schists and quartzites invaded by greenstone and rhyolite. There are similar deposits on the Yukon River below Dawson and on Rude Creek⁶¹⁸. Silver-lead-zinc veins occur also in the Laberge Series.

On the Canadian Shield the zinc and lead deposits on Great Slave Lake^{198 376} occur on crests of anticlinal folds in dolomite of Middle Devonian age.

In New Brunswick veins of galena and other sulphides cut the Silurian rocks along the coast of Chaleur Bay, and in Richmond County zinc-copper-deposits occur in a shear-zone of greenstones. In Nova Scotia^{292 353} and Cape Breton Island the lead and zinc deposits occur as replacements of volcanic rocks of Pre-Cambrian age which have been sheared into schists. In parts of Quebec the ore-deposits are found associated with a limestone-tremolite band in the Pre-Cambrian rocks, but in the Gaspé^{233 624} area they occur along fault- and brecciated-zones and joint planes in Lower Devonian beds, and especially along contacts with the intrusions of syenite. In Calumet Island, Quebec, the ores occur in lenticular masses replacing amphibolite of Pre-Cambrian age intrusive into Grenville rocks, and are developed along a shear-zone.

In south-eastern Ontario, zinc-blende, associated intimately with galena, is found as irregular veins, lenses or pockets, or along shear-zones, in the crystalline limestone and sediments of the Grenville Series or other Pre-Cambrian formations. In Newfoundland in the Buchans area^{486 510 530} there are ore-deposits of lead-zinc,

copper and silver, replacing tuffs and rhyolite-porphyry in a series of igneous rocks overlain by Carboniferous beds. In Placentia Bay the lead-zinc deposits are in fissure-veins in Pre-Cambrian silt stones or quartzites traversed by faults⁵³⁰.

Manganese²⁸².—This mineral occurs as pyrolusite, manganite, etc., in fissure veins in the granite of Lunenburg County, Nova Scotia, and of New Brunswick. It is chiefly associated with the limestones of the Windsor Series of Lower Carboniferous age. Manganese of the carbonate type occurs at Conception and Trinity Bays, in Newfoundland^{462 530}, in Cambrian rocks, as nodules, lenticles, or disseminations on one horizon, and is apparently of sedimentary origin.

Mercury.—In the Kamloops Lake area, and elsewhere in British Columbia, cinnabar occurs in fissures traversing the Tertiary volcanic rocks.

Molybdenite.—This mineral occurs as segregations in the syenite of the Arnprior-Maniwaki area²⁷³, but the most important deposits in that district are those of the 'contact-metamorphic type,' where the Grenville limestone is in contact with pegmatite, granite, and quartz syenite. In the Fleur-de-Lys area, Newfoundland⁵³⁰, it occurs at the contact between serpentine and gneiss. In the Rencontre East area of Newfoundland³²² there are also some molybdenite deposits⁵³⁰ in connection with granite intrusions into a series of lavas, chiefly rhyolites. In the Hazelton district¹⁸⁰ and Portland Canal area³³⁴ this mineral is of some importance, and occurs in the Hazelton (Upper Jurassic and Cretaceous) Series in veins. Near Falcon Lake, Manitoba, it is found as a constituent of typical pegmatite dykes or in granitic dykes or quartz-veins, cutting the Keewatin and Laurentian rocks.

Nickel.—The nickeliferous pyrrhotite of Sudbury^{7 7a 70 71 86 90 174 258 284 301-C302 303 331 371 500 564}, Ontario, occurs in connection with the intrusive sheet or laccolite of norite-pegmatite. This mass is found to have sometimes a dyke-like, but sometimes a sheet-like form, and is estimated to extend over an area of 500 sq. miles, and to have a thickness of 1¼ miles. It has forced its way between the Animikie (Upper Huronian) beds and the underlying older rocks, for it belongs itself to the post-Huronian Keweenawan Series. The molten mass has differentiated itself into three distinct layers, an upper layer of micro-pegmatite or fine-grained granite, a middle layer of norite containing some pyrrhotite, and a lower layer of rich nickeliferous pyrrhotite ore. But its mode of origin is disputed^{174 301a-c}. The ore-bodies mostly occur along the margins or as 'offsets' which are of the nature of mineralised dykes; the ore also occurs as sulphides.

cementing, impregnating, or replacing crush-breccias at the junction of the norite with the surrounding rocks. The size of the ore-bodies is immense. After the intrusion of the laccolite the floor sank, and the strata were thus folded so as to form a shallow elongated synclinal basin.

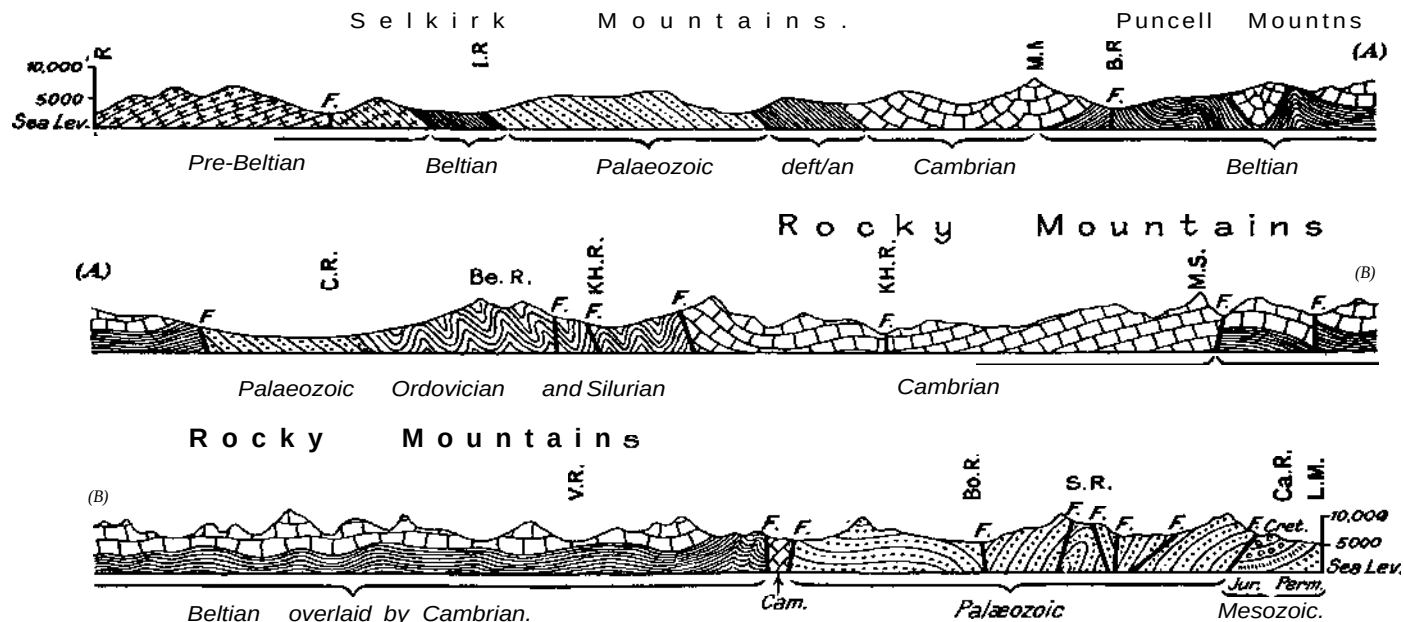
The nickel appears to be mostly present as irregular grains of pentlandite. The predominant sulphide mineral is pyrrhotite, but chalcopyrite also occurs to a considerable amount, and the ores carry not only nickel and copper but also small amounts of gold, silver, platinum, and palladium. Near Choate in the Yale district, B.C., nickeliferous copper sulphides are disseminated in hornblendite invaded by diorite.

At Alexo in northern Ontario, nickeliferous pyrrhotite occurs at the contact of a mass of serpentinised peridotite, which is intrusive into an altered andesitic lava-flow, and in its nature and mode of origin appears to be similar to that of Sudbury. At Calumet in Quebec, and near St. Stephen, New Brunswick, nickeliferous pyrrhotite likewise is found in connection with intrusions of diorite and gabbro. In Newfoundland⁵³⁰ copper-nickel sulphides are known from many parts of the serpentine belt on the west and north coasts.

Pitchblende (Uraninite)^{309 481}.—At Labine Point, on the east side of Great Bear Lake^{309 355 364 481 638}, pitchblende deposits are found associated with silver-ore⁶³⁷ in shear- and shatter-zones of altered rocks, including a complex of tuffs, conglomerates, sandstones, quartzites, iron-formation, limestone, and dolomite^{481 549}. A great variety of other minerals occur in the same deposits^{309 481 637}. The rocks in which the ores occur are referred to the Pre-Cambrian and, according to Kidd and Haycock⁴⁸¹, consist of a basal series of altered sediments followed by volcanic rocks, chiefly andesites, constituting the *Echo Bay Series*⁶³⁸. On them rest red tuffs with interbedded sandstones and conglomerates, forming the *Cameron Bay Series*. All are pierced by intrusive masses of granite and later diabase. At Contact Lake^{295 317}, to the south-east in the same area, similar silver and pitchblende deposits are found in a shear-zone cutting a dioritic rock, and in the Lake Athabasca region³⁴⁵ in dolomite of the *Tazin Formation* of Pre-Cambrian age. Uraninite also occurs in Ontario³⁰⁹ and other parts of the Canadian Shield in pegmatites of Pre-Cambrian age.

Platinum.—Platinum has been chiefly worked in the ' gold placer ' deposits of British Columbia²⁹⁶, especially in the Tulameen River district³²⁶, and on the Yukon and its tributaries. It has been derived from the intrusive peridotites and pyroxenites.

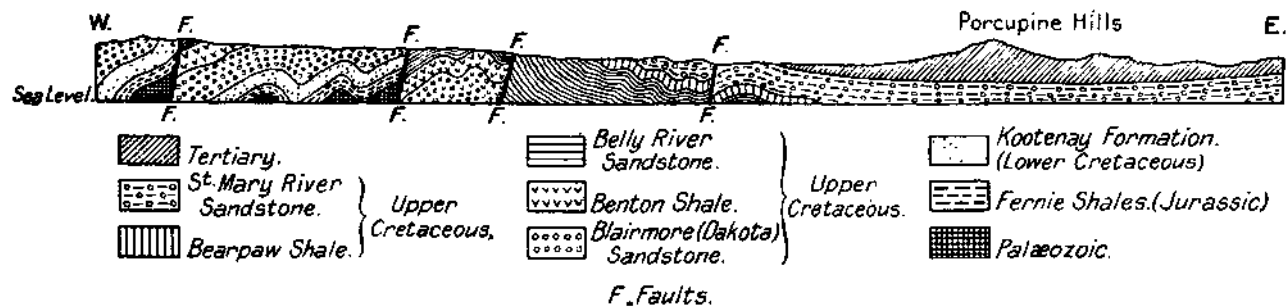
The mineral also occurs in the nickel-copper ores of the Sudbury district, Ontario, as above mentioned.

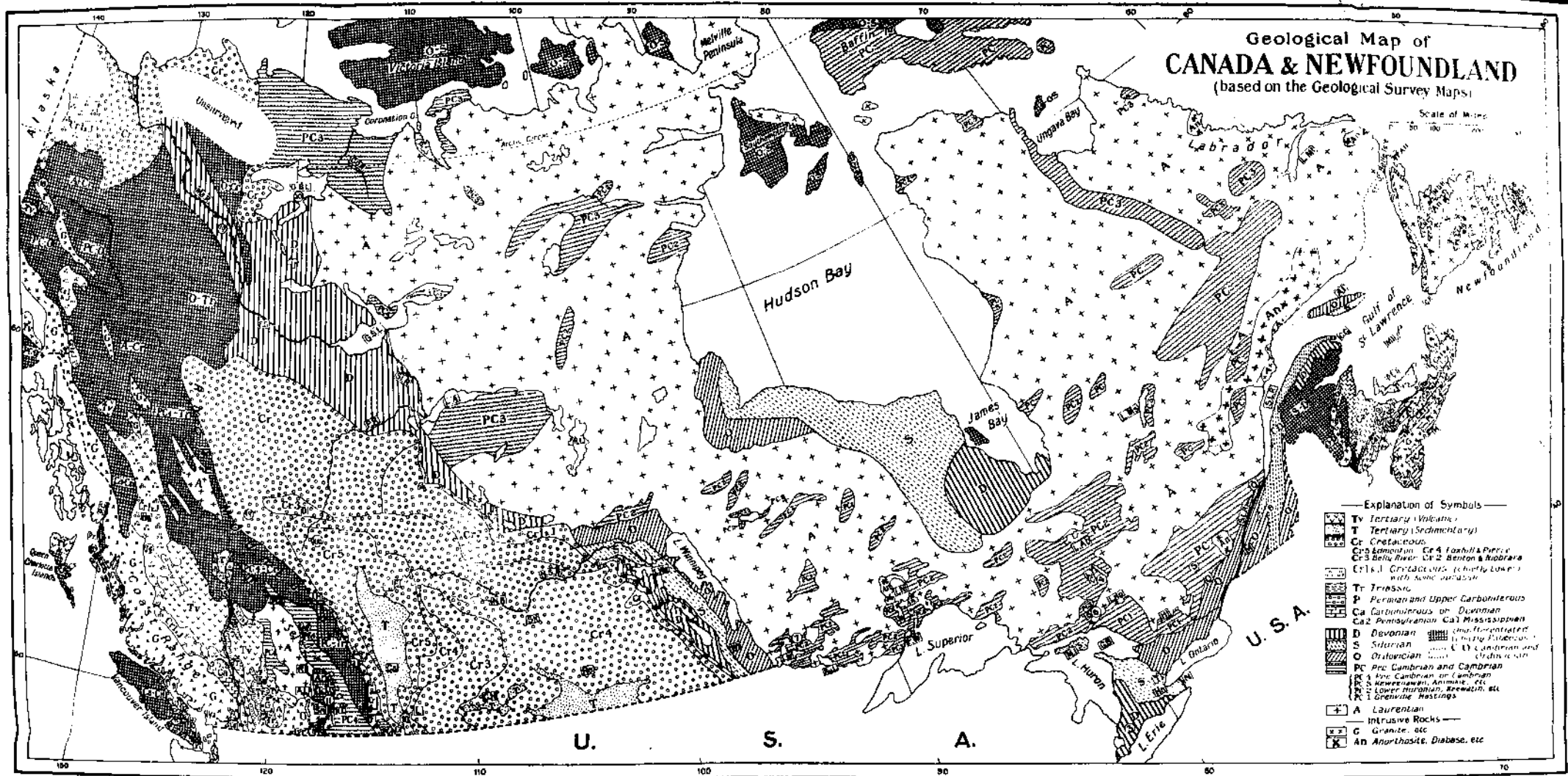


REFERENCES

B.R.	Beaver River.	Cas.R.	Cascade River.	L.M.	Lake Minnewanka.	S.R.	Sawback Range.
Be.R.	Beaverfoot Range.	I.R.	Illecillewaet River.	M.M.	Mount Sir Donald.	V.R.	Vermilion River.
Bo.R.	Bow River.	K.H.R.	Kicking Horse River.	M.S.	Mount Stephen.	F.	Faults.
C.R.	Columbia River.	L.L.	Lake Louise.	R.	Revelstoke.		

FIG. 15.—GENERALISED SECTION ALONG THE CANADIAN PACIFIC RAILWAY FROM REVELSTOKE TO LAKE MINNEWANKA.
(After Daly and Allan.)





REFERENCES

A. Annapolis.	C.R. Coppermine River.	G.B.L. Great Bear Lake.	L. Lethbridge.	M.R. Mackenzie River.	O. Ottawa.	Sy.L. Rainy Lake.	Su. Sloan.
A.I. Anticosti Island.	C.P. Chilliwack Pass.	G.S.L. Great Slave Lake.	L.A. Lake Athabasca.	M.I. Magellan Islands.	P. Pictou.	Sydney, Cape Breton Island.	T. Toronto.
A.L. Arrow Lakes.	C.R. Cape Ray.	H. Halifax.	L.A. Lake Abitibi.	M.I. Gulf of St. Lawrence.	P.C. Portland Canal.	S. Sudbury, Ontario.	T.I. Texas Island.
Ar. Arrowshead.	D. Dawson.	H. Hamilton.	L.M. Lake Mistassini.	M.I. Manitoulin Island.	P.E.I. Prince Edward Island.	S.J. St. John, New Brunswick.	Va. Vancouver.
Ba. Banff.	E. Edmonton.	H. Haliburton.	L.N. Lake Nipigon.	M.R. Mount Robson.	P.R. Peace River.	W. Windsor.	Vi. Victoria.
C. Chibougamau.	F. Fernie.	H. Hamilton.	L.N. Lake Nipissing.	N. Niagara.	Q. Quebec.	W. Winnipeg.	W. Winnipeg.
Ca. Cadzow.	F. Fraser River.	J. Joggins.	L.T. Lake Timiskaming.	N.B. North Battleford.	R. Revelstoke.		
C.B. Capetown Bay.	K.S. Fort Simpson.	J.H. Jasper House.	L.W. Lake of the Woods.	N.D.R. Notre Dame Bay.	R.L. Regina.		
C.C. Cape Gaspé.	F.W. Fort William.	K.L. Kootenay Lake.	M. Montreal.	N.S.R. North Saskatchewan River.	R.L. Reindeer Lake.		
C.H. Cypress Hills.	G.B. Georgian Bay.						
C.L.R. Columbia River.							

CHIEF LOCALITIES OF ECONOMIC MINERALS

1. Sydney Coal-field.	10-10a. Alberta Coal District (between these two places).
2. Inverness Coal-field.	11. Silver-lead (Ore). Kootenay District.
3. Stellarton Coal-field.	12. Teanade Island Copper Mines.
4. Joggins Coal-field.	13. Neasmead Coal-field.
5. Nova Scotia Gold District.	14. Talcott River Coal-field.
6. Ontario Salt and Oil District.	15. Fraser River Gold-fields.
7. Cobalt Silver District.	16. Klondike Gold-fields.
8. Asbestos Mines District.	17. Wabana Iron Ore, Belle Island, Newfoundland.
9. Sudbury Nickel-Copper Area.	18. Yukon Coal-field.
10. Lake of the Woods Gold District.	19. Chibougamau, along K-thall of Rockies.
11. Quebec Asbestos Mines.	20. Pitchblende, Great Bear Lake.
12. New Brunswick Coal-fields.	

Silver.—The mineral is generally associated with lead and zinc, as described under that heading, and occurs in rocks of many ages in Canada in veins and shear-zones or as replacements in beds from Pre-Cambrian to Cretaceous⁵³³. The chief producing area is that of Cobalt^{22 39 170 183 184 501 520 533 582 587 596} and Gowganda^{567 567a}, Ontario, where the Pre-Cambrian Cobalt Series of beds is overlain by the Nipissing diabase (with an intrusive contact) and usually rests with a strong unconformity on the Keewatin schists, as well as on the Timiskaming Series. The cobalt-silver veins, which have an average width of 4 ins., occupy practically vertical fissures or joint-like cracks in these three series, but are most numerous and richest in the Cobalt Series. Ore-shoots occur also along faults and joint-planes. There is a genetic relation between the silver deposits and the Keweenaw (Nipissing) diabase in Ontario²⁹⁸. The veins have originated probably²⁹⁸ by hydrothermal action after the intrusion of the Nipissing diabase and after the folding and faulting of the rocks, and carry native silver, argentite, smaltite, niccolite, etc.

In the Port Arthur district, Ontario, silver-bearing fissure-veins traverse the Animikie slates near the intrusion of the Keweenaw diabase, and on Silver Islet in Thunder Bay³³² there is a famous vein, which was only productive where it traversed the gabbro-norite or diabase piercing the Animikie beds⁵⁸⁷. In the Salmon River area, B.C.^{208 300}, native silver as well as argentiferous galena occurs in veins. There are many argentiferous deposits in the Kootenay^{260 292 329} district, as mentioned in connection with the lead and zinc ores with which the silver is associated. The Ainsworth Series¹⁹⁵ of pre-Carboniferous limestone and the Slocan Series of Upper Carboniferous argillites and limestones in the Ainsworth area²⁶⁰ are traversed by the silver-lead veins. Around Slocan^{195 339 340} the mineral is extensively worked. In the Lardeau area³²⁹ the silver ores are found as contact or replacement deposits. Farther west, in the Kicking Horse Pass district^{292 312}, there are silver-lead ore bodies in the Middle Cambrian along fissures in the limestone; between Lillooet and Prince George²⁹⁶, and in the **Bridge** River map area²⁷⁰, deposits of importance are also found, and these appear to be connected with the Coast Range intrusives. In the Beaverdell area, near Penticton, silver ore occurs in shear-zones traversing quartz-diorite intrusions of Jurassic age¹⁹⁵. In the Skeena River district²⁰⁷ and Portland Canal area³³⁴ silver associated with gold and many other minerals occurs in veins in **silicified** rocks of Jurassic age penetrated by masses of quartz-diorite and quartz-porphyry belonging to the Coast Range batholith. **Rich** silver-bearing veins also occur in the Yukon Territory^{206 618} in fissures, usually in basic porphyrites, but also in mica-schists and

quartzites. In the Keno Hill, Mayo district²⁰⁶, the deposits occur in fissure-veins of two different ages, and in the Wheaton River district the veins mostly occur in the igneous rocks of the Coast batholith. Elsewhere the deposits are found in veins traversing Mesozoic rocks, usually of a volcanic nature. In the Whitehorse district²⁴⁷ there are gold-silver quartz-veins in granitic rocks and in the Coast Range intrusives, with antimony-silver veins in fissures in the same rocks and in the andesites and volcanic breccias of the Older Volcanics of earlier Mesozoic age; there are also silver-lead tabular deposits in the Laberge Series. In Newfoundland silver is associated with lead-zinc deposits in fissure-veins or replacement deposits in connection with granitic intrusions of Pre-Cambrian age, as in Placentia Bay⁵³⁰; most of the silver here, as in British Columbia, is obtained from argentiferous galena.

Silver-lead deposits of importance are found in the Hazelton district¹⁸⁰, the ore occurring in veins in the Cretaceous tuffaceous sediments of the Hazelton Series, generally near igneous intrusions.

Tin.—The tin-bearing pegmatites, which are the latest intrusive rocks in the sedimentary Pre-Cambrian in one area of eastern Manitoba⁶⁰³, constitute one of the few stanniferous occurrences in Canada. The ore in this case is cassiterite.

Tungsten.—Some quartz-veins cutting the 'Gold-bearing Series' of Pre-Cambrian rocks in Nova Scotia carry scheelite and mispickel, but are not auriferous. Other quartz-veins carrying wolfram occur in New Brunswick. Scheelite occurs in important quantities in certain stream gravels in the Yukon. Wolfram is found also in the Hazelton district.

Zinc.—See under 'Lead.'

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CHAPTER X

INDIA, BURMA, AND CEYLON

SECTION I.—INDIA AND BURMA

General Geological Characters.—From a geological point of view India^{145 250 879}, apart from Burma¹⁹⁹, which has distinctive characters, consists broadly of two utterly dissimilar areas which have had a completely different geological history. These areas have been termed the Peninsular and the Extra-Peninsular areas^{1-3 379}.

(1) The Peninsular area consists of the triangular mass of land south of the Indo-Gangetic Plain. It is one of the few masses of land on the globe which seem to have remained above sea-level since, at any rate, Palaeozoic times, so that, with the exception of a few marginal Cretaceous deposits, all the post-Palaeozoic Formations found on its surface are of terrestrial or fresh-water origin. Its existence as a land mass may indeed date back even to pre-Cambrian times, for there are no fossiliferous marine beds of Palaeozoic age known upon it.' There is also no evidence that orogenic movements of any intensity have affected it during this long period, the strata lying horizontal or only gently undulated, with a few local exceptions. The topographic features are the results of the long-continued sub-aerial erosion of an old land-surface, and are mostly independent of the geological structure. Till late Cretaceous or early Tertiary times, it formed part of a great land mass spreading over much of the southern hemisphere, and known as Gondwanaland.

(2) The Extra-Peninsular area on the other hand comprises all the hilly and mountainous country to the north, north-west, and north-east of the Indo-Gangetic Plain, including the Himalayas and the frontier ranges, so that the area extends from Afghanistan and Persia on the west to China and Siam on the east. Marine deposits embracing the whole geological succession from the Cambrian upwards to Tertiary times are developed more or less completely throughout this vast area, and the beds are in most parts much disturbed, having suffered movements of great intensity at more than one period, which have produced folding, compression, and faulting on a large scale. But the enormous geosynclinal in which

' The Lower Permian marine fossiliferous beds in the Rewah State belong to an indentation in the northern margin of the Peninsula.—E. H% P.

this long succession of marine beds accumulated was not destroyed till Middle Tertiary times.

In this disturbed Extra-Peninsular region there is an intimate connection between the direction of the mountain chains and the lines of tectonic structure and elevation. The comparative youth of the surface-features is also exemplified by the features of the river-valleys ; and the dependence of topography on structure is everywhere a conspicuous character. On the other hand, in Peninsular India the hill ranges are not coincident with axes of elevation (except in the case of the Aravallis), but are merely the scarps of plateaus or remnants of table-lands, being essentially the products of prolonged sub-aerial denudation (*e.g.* the Vindhyan and Satpura ranges and the Western Ghats). This fundamental difference is of considerable importance.

Two distinct geological records are thus placed side by side in India³, and their mutual correlation, particularly in the case of the unfossiliferous or non-marine formations of Peninsular India, has always been a matter of difficulty. The European standard scale is, moreover, not easily applied to the Indian succession owing to differences in the development and history of the two areas, and the stratigraphical names which can be employed must largely be local, owing to these uncertainties of equivalence. The differences which are invariably connected with the existence of zoo-geographical provinces complicate the problem.

The nearest approach to correspondence in development and contents is naturally found among the marine formations, and as a starting-point the universal fixed datum-line of the *Olenellus* zone is fortunately recognisable in a few places in Extra-Peninsular India, though it has not been discovered in the Peninsula. Below this horizon there are many thousands of feet of unfossiliferous strata and metamorphic rocks to which we can only apply the names pre-Cambrian or Archaean. These comprise two main groups, *i.e.* firstly, the great mass of gneisses, crystalline schists, and plutonic rocks forming the old floor, and, secondly, the group of unfossiliferous, but clearly sedimentary, rocks resting upon them, and chiefly developed in the Peninsula.

Above the *Olenellus* line in those Extra-Peninsular districts where it has been detected we find, firstly, a series of beds belonging to all the well-known European systems from the Cambrian to the Carboniferous (though there are no records of this period in the Peninsula), and, secondly, a series of deposits ranging from Permo-Carboniferous, or Permian, to Tertiary with indications of frequent crustal movements. This latter series corresponds in a general way with a less complete succession of mainly terrestrial or fresh-water deposits in Peninsular India.

From this outline it is seen that we may recognise four main stratigraphical groups of Indian rocks. The oldest, which comprises the great mass of gneisses, etc., corresponds in a broad sense with the Archaean, and is termed by Holland⁶ the **Vedic**; the next group has been called by the same geologist the **Purana** Group, and includes many isolated local series of rocks resting with a great unconformity on the Archaean, and all unfossiliferous. The beds of this group are often scarcely disturbed and never foliated. In the Extra-Peninsular area the extent of their stratigraphical representation is at present unknown. They correspond apparently with much of the Pre-Cambrian of British or Algonkian of American geologists, and their relations seem to be identical. Fermor²⁰³ and Pascoe use the term Purana to include all the unfossiliferous formations above the Eparchaean unconformity.

The other two later groups of Indian rocks correspond with the Palaeozoic, Mesozoic, and Cainozoic of the ordinary European classification. But the first pronounced break is towards the end of the Carboniferous, and this fact caused Holland to put together all the beds upwards from the Cambrian to it into a third special Indian group which he calls the **Dravidian**.

The last and fourth group above this widespread interruption in the sedimentation embraces all the other post-Palaeozoic deposits and is called by him the **Aryan**.

The distribution of these stratigraphical groups is noteworthy. In the Peninsula there is a complete gap between the uppermost Purana and the lowest Aryan. But the intermediate Dravidian group is present in the Salt Range, Chitral, Kashmir, and the Central Himalayas, where on the northern side of the central axis of the range we find a more or less complete succession of marine fossiliferous strata. In Burma also the Dravidian is present, and there is no break between it and the Aryan. The Aryan is also spread over the same areas, being represented by further marine deposits laid down in the great central sea or 'Tethys' till Miocene times, when fresh-water deposits mostly take their place. On the other hand, in the Peninsula the Aryan is represented first by widespread terrestrial or fresh-water beds, and then by marginal marine deposits which were laid down only in the coastal regions during Upper Jurassic and Cretaceous times, when the southern continent began to show signs of dissolution. A great outpouring of lavas (the Deccan traps) followed immediately afterwards, and lasted into early Tertiary times accompanied by the deposition of some minor fresh-water formations. In Sind and Rajputana marine Cretaceous and Tertiary sediments were accumulating during much of the same time.

It was only in the early Tertiary (late Aryan) period that the

Himalayan region emerged as a land area and gradually drove back the ocean which had covered it almost uninterruptedly from early Cambrian times (see below). But its history is complex.

A large number of local names¹¹⁴ have been applied at different times to the various geological formations in different parts of India. Many have dropped out of use, but others must be retained owing to the above-mentioned difficulties or uncertainties of correlation with the European standard, or because they are useful locally.

' **Palaeontology**.—The numerous volumes of the *Palaeontologia Indica* may be specially consulted for descriptions of the various fossil faunas of India. References to particular works are given in the following account of the successive formations. The ' *Memoirs* ' and ' *Records* ' of the Geological Survey of India are the chief source of our knowledge.

DETAILS OF THE STRATIGRAPHY

GROUP 1.—VEDIC ERA⁶

Archaean.

PENINSULAR INDIA.—The basal crystalline and metamorphic rocks are exposed at the surface over a larger area than all the newer formations put together, covering more than half its extent. They form a complex assemblage of many petrological types, some being of sedimentary, but others of igneous origin. Some are merely plutonic rocks deformed by pressure and subsequent movements ; others are altered volcanics, and others again retain the essential character of well-known sediments, and differ from them merely in mineral character, structure, and texture owing to metamorphism. All are more or less folded, and nappe structures are present occasionally⁴¹⁰. The origin of some others is still doubtful. Holland⁶ drew up a provisional classification of the Vedic rocks of India as follows :—

5. Post-Dharwar eruptives.
(*Irruptive contact*.)
4. Dharwar System.
(*Unconformity*.)
3. Bundelkhand type of deformed eruptives.
(*Irruptive contact*.)
2. Bengal type of schists.
1. Oldest gneisses.

This classification brings into close correlation the succession of Archaeal and pre-Cambrian rocks in North America and India, and Dunn⁸⁴⁹ later put forward another correlation of the Archaeal of Peninsular India with that of other countries. But whether this will hold good with a further advance of knowledge is questionable, and for the present we may only say that in India there appears to be on the whole an older division of gneisses, schists, etc., forming a pre-Dharwar Group, and a later division known as the **Dharwar** System, separated by a great unconformity. Associated with both these divisions of foliated rocks are batholiths of igneous origin, some of which possess relationships to the older division like those of the Laurentian to the Keewatin and Grenville Formations in Canada, while others invade also the

Dharwar, and therefore seem to correspond with the Algoman-Lorraine intrusives of Canada (*q.v.*), and are post-Dharwar in date. To the oldest gneisses may be ascribed the 'fundamental biotite-gneisses' of the Salem district, Madras, as Holland has shown on definite geological as well as petrological grounds⁷. But the relative ages of all the Archaean rocks is still variously interpreted²⁶⁴.

Several more or less distinct lithological types or facies of the pre-Dharwar crystalline rocks have been recognised. Vrendenburg² distinguished three such types:—(1) the Bengal gneiss (Oldham), (2) the Bundelkhand gneiss (Mallet), and (3) the Nilgiri or Mountain gneiss (King), though their relations and ages are in some cases uncertain. Fermor²⁰⁸ has recently proposed a classification based chiefly on the petrological characters of the rocks as far as Peninsular India is concerned, and has applied it to the formations of the Archaean below the Eparchaean unconformity.' He recognises two main regions :—

The first is the '*Non-Chamockitic region*,' comprising three provinces :—(1) the Iron-ore province ; (2) the Manganese-ore-marble province; and (3) the Bundelkhand province. The first province is represented by the Dharwar type; the second by the Central Provinces type, and the third by the igneous rock type.

The second region is termed the '*Chamockitic region*,' and has three corresponding lithological provinces, represented respectively by the Salem type, the Nilgiri type, and the Eastern Ghats type^{197 811}.

The Extra-Peninsular region he has divided into the Himalayan type, the Central Provinces type, and the Kumaon-Garhwal type. The Burma type is represented by the Mogok rocks. Various minor subdivisions of each type can be recognised. The pre-Cambrian age of the various igneous intrusives, in so far as they yield radio-active minerals, has been estimated by the lead and helium ratios by Holmes³⁵⁰ and others.

There is such a varied development of these Archaean rocks in different areas that local names and classification are necessary, and at present it seems premature to adopt any detailed correlation between them²⁵⁰.

(1) The **Bengal** type of gneiss includes schistose and banded gneisses and various rocks of metamorphic origin, such as the peculiar magnetite- and associated schists and the iron-ores of Salem⁷. The gneiss is characterised by its varied composition and conspicuous banded structure. It often exhibits rapidly alternating layers of sharply contrasted composition, some of which show the features of gneissose granites or diorites, while others are more of the nature of schists. The schistose types are very numerous, and include quartzose, micaceous, and hornblendic schists, and garnetiferous, sillimanite-, magnetite-, and manganese-bearing schists. The Bengal facies occupies large areas in Bengal, Bihar, Manbhum¹²⁸, Orissa, Rewah, and Gujarat. By some geologists it is correlated with the Keewatin of Canada.

(2) The **Bundelkhand**²⁸⁸ type of gneiss is massive and coarse, with the appearance and composition of a pink granite. It is traversed in its type-area (Bundelkhand in Central India) by great veins of quartz which stand out as ribs on the surface of the ground. There is a comparative absence of schists in this facies. Whether this type is comparable or not with the Laurentian of Canada is a matter of doubt. But it has been claimed by some to be intrusive-into the Bengal gneiss. The Bundelkhand type of gneiss is found in several

⁷ For a detailed summary of the various views advanced concerning the classification of the Indian Archaean, see Chapter III of the Third Edition of *The Manual of the Geology of India and Burma*, now in the Press.—E. H. P.

other parts of the Peninsula, and is known by local names (Bellary Gneiss, Arcot Gneiss, etc.).

In southern India this type is represented by the massive granitoid red gneiss particularly developed in North Arcot, in the Cuddapah district, in the eastern part of the Bellary¹² district, in the Kurnul district, and all over the eastern portion of Hyderabad up to the higher reaches of the River Godavari, and includes the Balaghat and Hosur gneiss. It seems to bear the same irruptive relation to the other Archaean rocks as does the Laurentian in Canada, but we cannot say that all these granitic masses are of the same age.

In EXTRA-PENINSULAR INDIA the central gneiss of the Himalayas forming the axis of the highest range is only in part of Archaean age, for granites of much later date²⁷⁶ (including some of Tertiary age) and metamorphosed post-Archaean sediments have been included with it.' This metamorphic axis of the mountains constitutes a central zone extending from the Karakoram and Kashmir ranges eastwards to Burma, and forms a complex of rocks but little investigated. In Sikkim⁴⁰⁹, near the eastern end of the Himalayas and around Kanchenjunga, the gneisses, schists, granites, and quartzites may in part be of Archaean age, but the crinoidal limestone folded in with them is probably of Palaeozoic age.

In consequence of our present imperfect knowledge, it is not possible to determine in each case, even in the Peninsula, the relative ages of the above-mentioned two types of gneiss, but together they may include the oldest rocks in India, in a broad sense referable to the Archaean of other parts of the world.

(3) The third type of gneissic rocks, mostly of definite eruptive character, has been termed the **Nilgiri Gneiss** and constitutes some of the most important hill masses in the Deccan and southern India, including the Nilgiri Hills. These rocks closely resemble later intrusions, except for the size of their outcrop. They are mostly granitoid rocks of a peculiar dark-grey or black colour characterised by the constant presence of the mineral enstatite. Some also contain garnet and others quartz. The less siliceous members belong to the class of norites, and others approach diorites and granites. Amongst them are the norites of Coorg and the enstatite-granulites or charnockites⁷ⁿ of Madras, Bastar, and Orissa³¹¹, forming the 'Charnockite Series',^{197 3U}; these rocks belong to a rare type, but co-magmatic regions comparable with that of southern India have been recognised in Norway, Ellesmere Land, New York, Virginia, and West and East Africa¹³⁰. Probably the anorthosites of Bengal may be referred to the same group. All these are regarded as intrusive into the other Archaean rock-masses.

In Rajputan^{233 234 263 265 266 284 382} the crystalline and metamorphic rocks of the Archaean and Pre-Cambrian have been carefully investigated and can be satisfactorily divided into four groups, all of which are separated by unconformities and conglomerates. In north-east Rajputana³⁵⁸ a banded gneissic complex, which is supposed to be equivalent to the Bundelkhand gneiss, forms the base. Intrusive granite and other igneous rocks penetrate the system.

Dharwar System.—The Dharwar System forms many series with local names in the Central Provinces, Mysore, and parts of Madras, and these are included by Holland in the Archaean, though Vredenburg² puts them in his 'Transition Group,' together with the Cuddapah System (see below). According to

' It is doubtful whether any of the gneiss in the Himalaya is as old as the Archaean.

Smeeth the oldest rocks of the Archaean complex in the Mysore State belong to the Dharwar System, and the granite-gneisses, hitherto regarded as pre-Dharwar, are there intrusive in it, and belong to at least four successive groups, including Holland's charnockites.

The Dharwar System consists of many penological types, including quartz-haematite-schists, quartzites, hornblendic, talcose, micaceous, and chloritic schists, jaspilites, banded jaspers, phyllites, beds of steatite, manganese-ore, iron-ore, and conglomerates; and the rocks, which are chiefly of sedimentary origin, have suffered considerable metamorphism. In the type-area the beds are folded into the older gneiss in a series of narrow elongated synclinals, but the structure is complex. There is no clear evidence of a physical unconformity with the gneiss, but pebbles of gneiss occur in the Dharwar conglomerates, though these may be autoclastic. Limestones are very rare; those in Nagpur and Chhindwara are manganiferous. Locally there is evidence of contemporaneous igneous activity in the presence of undoubted lava-flows and ash-beds, and in Mysore it is believed that all the hornblendic and chloritic schists are crushed volcanic rocks. The system is well developed in the Dharwar area, including the Bellary district¹², in Mysore, in the Central Provinces, and in the Aravalli region²⁶⁵.

Economically it is of much importance as carrying the chief gold reefs of India; in the Kolar gold-field¹⁷, Mysore⁴⁵⁵, the auriferous quartz-reefs traverse the hornblende-schists which there make up the bulk of the Dharwars and have mainly originated from the metamorphism of basic lava-flows. There are also massive deposits of manganese ores (*e.g.* in Madras) and of haematite and magnetite in many other parts which are likewise of much importance. Some uncommon types of rock, such as the flexible sandstone³⁹¹ of Kalia, near Dadri in Jind, are also found in the Dharwar System.

The banded quartz iron-ore rocks of the Mysore State are widely spread, and are very similar to those of the Lake Superior region. Many of the greenstones and schists also appear to resemble those of the Keewatin rocks of Canada. The Iron-Ore series in Bihar and Orissa²¹⁸ and Singhbhum^{890 401} belongs to the newer Dharwars, and consists of a varied series of conglomerates, sandstones, quartzites, shales, and banded haematite-quartzites containing the bodies of iron-ore. This Iron-Ore series was at first thought to rest unconformably on an older series of metamorphic rocks, but this is doubtful; it is overlain by altered basalts and other volcanic rocks. The petrology of the Dharwar rocks in Kodarma Forest, Bihar, has been investigated by Sharma³⁹¹; in this area the so-called 'Dome gneiss' is intrusive into them. The conglomerates of Dharwar age in Mysore⁴⁰² are regarded as true detrital deposits which have suffered subsequent crushing.

In the Aravalli⁹ range in Rajputana^{234 262 265 268 428} and Gujarat, rocks of some of the same types are exposed. The Aravalli range²⁸⁴ seems to be the oldest in origin in India, for, according to Fermor⁴²³, it was formed as a fold-range in pre-Vindhyan times, and after long erosion was rejuvenated as a horst in post-Vindhyan times. In the Idar State⁴⁸⁸ Middlemiss²⁶² has given a detailed description of the *Aravalli System*²¹¹, which consists there of a mixed assemblage of foliated crystalline rocks without any detected serial order. Outcrops of the same system occur in the Central Provinces in the Nerbada district (*e.g.* the Jabulpore 'marble-rocks'), in Bihar (Kharakpur hills), in the Balaghat district, between Midnapore and Nagpur, and elsewhere.

¹ The Aravalli and other rock systems of Rajputana have been described in great detail by Heron, B. C. Gupta and others. See especially *Mem. Geol. Surv. Ind.*, vol. lxx., pt. 2 (1934); *ibid.*, vol. lxxviii., pt. 1 (1936); and *Bee. OeoL Swrv. Ind.*, vol. lxxiii., 163-208 (1938).—E. H. P.

It is in the pegmatite veins which pierce some of the plutonic intrusions of post-Dharwar age that the large muscovite crystals of commercial importance are found (see 'Economic Minerals'). Moreover, in the Aravalli Series of schists there are valuable lodes of copper, while this area is also famous for its building stones.

The sillimanite-bearing schists (Khondalites of Walker)^{105 197} in the Eastern Ghats may represent altered phyllites of the Dharwar System, and the manganiferous rocks (Gondite Series of Fermor¹⁶) of the Balaghat and Nagpur districts are regarded as metamorphosed sediments of the same age, but the important manganese deposits of Madras are considered to be altered plutonic intrusions (of the Kodurite Series of Fermor) which penetrate the Gondite rocks¹⁶. Gondite is a spessartite-quartz rock resulting from the metamorphism of sediments, but kodurite, which is typically developed in the Vizagapatam district of Madras, is due to the alteration of plutonic intrusions.

EXTRA-PENINSULAR AREAS.—In Extra-Peninsular India rocks of the same types as the Dharwars are found in various localities and bear local names, but may belong to widely different ages, and probably at any rate include some Purana rocks. Such is the *Vaikrita System*^{18 14} in Hundes, Kumaon, and Spiti, which consists of schists, phyllites, and gneiss occupying synclinals in the older (?) granitic gneiss. In Kashmir the equivalents of the Dharwars are known as the *Salkhala Series*²²⁴, which consists of slates, schists and phyllites, with crystalline limestones and quartzites interbedded. The schists are of various types, and the metamorphism of many of the other rocks has changed them into gneisses, some of which, however, represent intrusive masses. Nanga Parbat⁴³⁴ is mostly composed of a biotite gneiss together with other members of the Salkhala Series. In the Punch State of Kashmir the *Dogra Slates*^{224 251} overlie this series. In the Great Himalaya, west of Ladakh, the Salkhala Series is more metamorphosed and consists of para-gneisses. In Sikkim a similar series is known as the *Dating Series*, and on the Assam Plateau the rocks have been termed the *Shillong Series*¹⁸⁰, and contain basic interbedded traps amongst the schists. In Simla and the western Himalaya other local developments of metamorphic and crystalline rocks of this type with similar relations have received distinctive names. In the Simla area the most recent classification of the supposed Archaean formation has been given by Pilgrim and West¹⁸⁴, who term it the *Jutogh Series*. It is composed of four groups of quartzites, banded limestones, and schists, the order of which is not precisely settled. It may correspond broadly to the Dharwar Series, though this is by no means certain.

The Himalayan²⁰⁸ 20 297 348 394 399 408 409 470 central zone is mainly formed of crystalline and metamorphic rocks of many types, but most of them are of sedimentary origin and include beds of many ages, though the earlier view was that all the rocks were Archaean or pre-Palaeozoic. Our knowledge of the rocks composing the Himalayan zone is still very incomplete^{297 857 437 446 470}, only certain portions having been examined geologically, and in most cases only partially, such as Nanga Parbat^{399 434 458} in the west, and Mount Everest^{848 394 403} and Kanchenjunga⁴⁰⁹ in the east. The common idea^{297 869} that there is a central granitic axis to the Himalayas has been proved of late years to be not the general case^{276 857}, for the higher ranges and peaks are found to be composed of sedimentary rocks (slates, quartzites, crystalline limestones, etc.), though frequently represented by metamorphic rocks (gneisses and schists)^{821 359}.

' Some at least of the Vaikrita rocks have been observed by Auden to pass laterally into Haimanta beds and appear to be merely a more highly metamorphosed facies of the latter.—E. H. P.

In BURMA the crystalline rocks in the old Ruby-Mines district of Mogoke^{18 246} (about 90 miles north-east of Mandalay), bear much resemblance to some of the Dharwars of the Central Provinces. But while the Archaean age of these Mogoke rocks^{324a-c} has been generally accepted in the past, it has been suggested recently by Clegg²⁵⁶ that, at any rate, some of them may be metamorphosed Cretaceous, or even Tertiary, beds, and of the same age as certain rocks in the Irrawaddy defiles. The gneisses are of very varied character, including scapolite-gneiss, biotite-gneiss, augite-gneiss, enstatite-gneiss, etc., and are associated with granulites of several kinds, crystalline limestones, and schists. Garnetiferous granulites are the commonest rocks, but calciphyres, calc-gneisses, and calc-granulites abound, with some quartzites^{824c}. Intrusive granites, syenites, pegmatites, aplites, and basic rocks, often more or less altered, pierce these rocks in all directions. Though most of the intrusives are of an acid type, there are peridotites around Bernardmyo, and nephelinites occur also as minor intrusions^{324c}. The crystalline limestones (which may be of chemical origin) are interbedded or interfoliated with the gneisses, but mostly with the augite-and scapolite-rocks, and contain a great variety of minerals, including ruby, spinel, etc.^{19 405}. The garnetiferous granulites approach the feldspathic khondalites of Ceylon and Peninsular India³¹⁷, and the pyroxene-granulites show a marked similarity to the charnockites of southern India²³⁸. Adams²⁴⁶ has remarked on the striking resemblance of the Archaean rocks between Thabeitkyin and Mogoke to the Grenville Series of Canada. The whole series strikes almost due north and south, with a dip to the east. The enormous development of bedded limestones is one of the most remarkable features in the series.

The Coast Range and Dawna Range in the south of Burma consist of gneiss and schists, probably belonging to two distinct periods¹⁹⁹, but their age is uncertain. Part of the Mergui System may be as old.

Late Intrusions.—Of *post-Dharwar eruptives* there are granites, granite-gneisses, pegmatites, elaeolite-syenites, dunites, etc., occurring in the Peninsula. The Dome gneiss of Hazaribagh⁹⁴, the pegmatites of Rajputana, Hazaribagh, and Nellore⁸⁴, the elaeolite-syenites of Coimbatore¹⁵, Vizagapatam, and the Aravalli Range, perhaps the Kodurite Series of Fermor in the Vizagapatam district¹⁶ (containing manganese-bearing minerals, garnets, and apatite), and the peridotites or dunites rich in chromite and magnesia which form the 'Chalk Hills' in the Salem district^{7 95}, are examples of these eruptives. Quartz-porphyry dykes traversing pre-Purana rocks in various parts may also belong to this group, and in southern India the 'White Elephant Rocks' of the Shevaroy Hills, Salem, consisting of masses of white quartz, may be eruptives of this age.

Post-Archaean Tectonic Disturbances.—Great orogenic movements took place in the Peninsula and also in the mountain region at the close of Archaean times. The rocks were metamorphosed, folded, foliated, faulted, and elevated, and then suffered a long period of erosion before any later beds were laid down upon them. This period of disturbance and denudation corresponds to the so-called Epaercean interval of North America, which seems to have been of world-wide extent, and is marked by a great unconformity.

GROUP 2.—PURANA ERA

Pre-Cambrian.

PENINSULAR INDIA.—Upon the highly denuded surface of the much-folded Dharwars and older rocks of the Archaean (Vedic) there rest enormous thicknesses of comparatively unaltered and little-disturbed beds of sedimentary

origin which have so far yielded no fossils. In the Peninsular area the oldest fossiliferous rock which comes in superior contact with them is of Permo-Carboniferous age belonging to the Gondwana System. These rocks are developed in isolated areas, and have consequently received distinctive names, as their correlation is at present impossible.

In southern India there is the *Cuddapah System*²⁰, 20,000 ft. thick, in Central India the *Gwalior System*²⁶³, and just north of the Narbada the *Vindhyan System*, besides several smaller local ones. These rocks are usually grouped into an older and a younger division.

The older division contains the Lower part of the Cuddapah System, the Gwalior and Bijawar Systems¹¹⁵, while the later division includes the Upper Cuddapahs, the Kufnool Series, and the Vindhyan System.'

(A) The **Cuddapah System**²⁰ is developed in a large district situated about the middle of the Madras Presidency on the eastern side of the Peninsula and covers an area of 14,000 sq. miles. It consists principally of an alternating series of much indurated, but not metamorphosed, quartzites and slates, with subordinate limestones, conglomerates, and igneous rocks. The two main divisions (a) and (6), and the four subdivisions into which it is again split up, are all more or less unconformable to each other, and successively overlap and come to rest on the gneiss. All are unfossiliferous.

(a) The lower division of the Cuddapahs, comprising two subdivisions, contains numerous contemporaneous basic igneous rocks²¹; olivine-norites, augite-norites, and augite-diorites, with many transitional varieties occur amongst them, and of each there are noncrystalline and hemicrystalline representatives. Interbedded lava-flows and ash-beds, with sills, dykes, etc., point to volcanic action. Banded jaspers, jaspilites, and quartz-iron-ore schists are a feature of the Lower Cuddapahs, and to this extent link them petrologically with the Dharwars. The Delhi System may be of this age (see below).

The upper member of the Lower Cuddapahs, which is characterised by these igneous rocks, is widely spread throughout India, and in the State of Bijawar in Central India bears the name *Bijawar Series*¹⁵⁵. In Gwalior²⁶⁸ the corresponding beds are called the *Gwalior Series*. The basic lava-flows are conspicuous in both areas, with intrusive dykes, sills, etc., but the Bijawar Series in Bundelkhand also includes cherty limestones, quartzites, breccias, ferruginous sandstones, shales, and rich beds of haematite; the strata are usually quite or nearly horizontal. The Gwalior Series²⁶³ consists largely of porcellanites, jaspers, and hornstones, with volcanic rocks.'

Throughout the greater part of their outcrop the beds of the Cuddapah System in the type-area dip at moderate or low angles, or lie nearly horizontal, but along the eastern Ghats and south of the Son¹¹⁵ River, they are intensely compressed and folded.

(b) The Upper Cuddapahs in the type-area contain some remarkable conglomerates or boulder-beds, perhaps tillites, composed of sub-angular pebbles of various rocks and sizes lying in a slaty matrix, and it is noticeable that in South Africa, Canada, and Australia rocks of this character also occur in the Pre-Cambrian Groups¹³⁷, and are thought to be of glacial origin. Quartzites and slates with some interbedded limestones compose the rest of this Upper division.

Outside the type-area the Upper Cuddapahs are believed to be represented

' Heron has shown that the Gwaliors are less metamorphosed equivalents of Aravalli beds; to the latter formation he would also assign the Bijawar rocks which have every appearance of passing laterally into Aravalli sediments.— E. H. P.

by the *Kaludgi Series*^{117 330} in the south Mahratta country, 9000-15,000 ft. thick, and by the *Pakhal Series* on the Lower Godavari. The Kaladgi beds consist of conglomerates, quartzites, peculiar cherty breccias, shales, sandstones, and limestones, and rest quite unconformably on the older crystallines. The Pakhal Series of quartzites, etc., is 7500 ft. thick.

The *Kurnool (Karnul) Series* lies almost entirely in the basin of the Cuddapah System in southern India, but in two separate areas; it is separated by a strong unconformity from the Cuddapah System, and consists of about 1200 ft. of limestones with subordinate bands of shale and sandstone. The beds are almost undisturbed except along their eastern border. Some of the sandstones are diamantiferous. By some geologists it is considered to be equivalent to the Lower Vindhyan (see below).

(B) In the Aravallis⁹ of north-eastern Rajputana^{238 262 266 356 433} the so-called **Delhi System** rests with a great unconformity (Eparchæan) on the much older Aravalli System, and is distinct from the other post-Archæan formations of the Peninsula in its intense folding and amount of igneous intrusives. It is divided into several series, amounting in all to some 20,000 ft., and consists of a great variety of rocks, including quartzites, limestones, hornstone-breccias, slates, conglomerates, and contemporaneous volcanic rocks. The lowest member is the *Raiolo Series*^{233 256}, which consists largely of limestones, including the well-known Makrana marble. Several other divisions follow above it, chief of which is the *Alwar Series*³⁵⁶, consisting of quartzites, arkoses, conglomerates, and mica-schists, with some contemporaneous volcanic rocks, the whole having a thickness of 10,000-13,000 ft. In western Jaipur¹⁷⁴ similar much-folded and locally metamorphosed rocks are found. Intrusive in the Delhi System are pegmatites, granites, and amphibolites. Mount Abu in Sirohi State²⁶⁶ consists of such a mass of intrusive granite.

(C) The **Vindhyan System**^{22 22a 216 240 263} is developed in Rajputana^{268 240 420} and Central India north of the Narbada and Son Rivers, and south of the Jumna and Ganges, and in a single basin occupies a larger superficial area than any other formation in the Peninsula, except the Archæan and the Deccan traps. It is conspicuously displayed along the great escarpment of the Vindhyan Range. Sandstones are the predominant type of rock, and three of them are specially important. The strata, which have a total thickness of over 14,000 ft., as a rule dip only at low angles, and are even less disturbed than the Cuddapahs. The lowest division contains limestones and calcareous shales with remarkable concentric structures and there are also porcellanites formed from rhyolitic tuffs, while here and there felsites occur. In western Rajputana these volcanic rocks are known as the *Malani Series*^{3 240}, and consist of rhyolitic lavas with tuffs and breccias resting unconformably on the Aravalli schists. Around Jodhpur⁸ they spread over thousands of square miles, and connected with them are bosses of granite. In the Sirohi State²⁶⁶ the Malani Series or System occupies a position above the Delhi System, and includes plutonic, hypabasal, and volcanic rocks.

The Upper Division, which rests with a pronounced unconformity on the Lower and overlaps it, forms the chief mass of the formation; the latter consists of sandstones, shales, and conglomerates, but sandstones are the most abundant and important rocks, and mark distinct stages known as the Kaimur, Rewah, and Bundair (Bhander) stages. Some doubtful brachiopods and other obscure organic remains from the Vindhyan (Suket Shales) of Central India have been described by Chapman²⁰⁶ and Sondhi²¹⁷. But if their organic nature is confirmed we may have to put some part of the Vindhyan in the Cambrian²⁰⁸.

The Vindhyan is rich in building-stones, and the palaces of Gwalior, Delhi, Agra, Amber, and most of the masterpieces of Indian architecture have been built of materials from this system.

EXTRA-PENINSULAR INDIA.—In Extra-Peninsular India the reference of any rocks to the Purana Group rather than to the Vedic is somewhat doubtful¹⁸⁰. But Pilgrim and West¹⁸⁴ recognise two groups in the Purana of the *Simla area*, the lower of which consisting of schists, quartzites, phyllites, and banded limestones, is termed the *Chail Series*, and is invaded by a granite, the Chor granite, which in its turn is pierced by olivine-dolerite. The upper Purana, consisting of slates, phyllites, conglomerates, and quartzite, constitutes the *Jaunsar Series*, which is separated by an unconformity from the later *Simla Series*, of which they refer the upper part to the Lower Palaeozoic, consisting of dark unaltered slates and micaceous sandstones; the lower part consists of limestones. The *Blaini Conglomerate*¹³⁷ which used to be regarded as of Cambrian or pre-Cambrian age, is now^{184 242} referred to the Permo-Carboniferous, together with some other beds in the Simla area, the age of which had been much disputed^{14 112 113 184 242}. The *Krol Series*²⁴² of limestones and sandstones in the Simla district, which was formerly regarded as Pre-Cambrian, is now regarded by Pilgrim and West¹⁸⁴ and by Auden²⁴² to be of much of later date.

In the Central Himalayas the *Haimanta System*^{13 14} may perhaps be partly ascribed to the Purana (see p. 423). Farther east, near Darjeeling, there is the *Baxa Series* along the borders of Bhutan, consisting of magnesian limestones, quartzites, etc., which may also be of Purana age, and it is possible that the previously-mentioned *Shillong Series* of Assam should also be placed here rather than with the Dharwars.

In the Attock district the *Attock Slates*^{222 382} are regarded as representing some part of the Pre-Cambrian, or possibly part of the Cambrian, and have been correlated with the Simla and Dogra Slates. In the Gilgit area¹⁹¹ there occur granites, diorites, schists, quartzites, altered limestones, slates, etc., the relations and ages of which have not been precisely determined, but probably most are Pre-Cambrian. The '*Slate Series*' of Hazara⁸⁷ may represent the Attock Slates²²² of the Punjab and the *Dogra Slates* of Kashmir^{224 251}, which overlie the Salkhala Series in the Punch State²⁵¹.

In BURMA¹⁸ in the Northern Shan States there is a well-defined group of beds separated by a distinct stratigraphical break from the succeeding formation which has been called by LaTouche the *Taumg Peng System*. The lowest division consists of schists with intrusive granite (*Mong Long Group*). The middle, or *Chaung Magyi Series*, consists of quartzites, greywackes, slates, shales, and sandstones, but no limestone or conglomerate. The beds have a wide distribution, and are probably represented on the Burmo-China frontier⁸²⁴. They are said to resemble the Shillong Series of Assam (which has been mentioned in connection with the Dharwars and Puranas), and are intruded by great masses of granite, olivine-gabbro, etc. Before the Chaung Magyi beds were deposited there was a period of denudation of the Archaean rocks, and there was also an orogenic period after their accumulation when intense folding and faulting took place before the Naungkangyi (Ordovician) beds were laid down on their denuded edges.

The uppermost, or *Bawdwin Volcanic Series*, of the Shan States consists of ashes, fine tuffs, and rhyolitic lava-flows silicified and mineralised, or metasomatically replaced by sulphides of lead and zinc¹⁰⁶, copper, silver, and other minerals of great commercial importance (see 'Economic Geology').

In southern Burma, Tenasserim, and in the coastal islands of the Mergui Archipelago, the *Mergui Series*^{190 199 241}, which consists of phyllites, argillites,

shales, conglomerates' quartzites, limestones, tuffs, and agglomerates, is probably partly of Pre-Cambrian age, but its age is unsettled, and Scrivenor believed that part might represent the Malayan Trias. It is possible that some Palaeozoics may be involved in the complex folds, as the discovery of a species of Carboniferous or Permian spiriieroid in the Mawchi area²⁶¹ suggests (see under 'Carboniferous'). The beds are intensely folded, and their succession is at present undetermined; they strike N.N.W.-S.S.E., and have high dips. Granites and pegmatites invade them, and apparently were folded with them, for the granites form elongated bodies with the same strike in the Tavoy²⁴¹ district, where the whole series is extensively developed.

GROUP 3.—DRAVIDIAN ERA

EXTRA-PENINSULAR INDIA.

1. Cambrian.—With the exception of the occurrences in the Salt Range in the Punjab and in Spiti in the Central Himalayas and Kashmir,²²⁸⁻²²⁵ no indisputable Cambrian rocks have been found in India, though it is possible that some of the older metamorphosed or unfossiliferous rocks may ultimately have to be placed at the base of the Palaeozoic rather than with the Pre-Cambrian.

SALT RANGE^{23 24 302 327 383}.—One of the lowest beds in the Salt Range is known as the *Purple Sandstone*²²⁷. In the eastern Salt Range it is seen to rest on a mass of red marl¹²⁸ forming the *Saline Series*^{127 331 426 426a}, containing beds of salt and gypsum in places, but it has been suggested that this series may owe its position to earth-movements and to be of very much later age (Tertiary), the Cambrian beds having been thrust over it. The presence of fragments of the Purple Sandstone in the red marl and other features in connection with its occurrence tend to prove that its apparently simple relations are deceptive. There is, however, much difference of opinion as to its stratigraphical position and true age^{881b}. The discovery by Anderson of leaves of the Tertiary and Recent genus *Quercus*¹⁷⁶, and by Sahni^{381 881a-b} of angiospermous plant-remains and insects in the marly layers between the massive beds of salt-rock, appear to support a Tertiary age, and the whole combination of salt and marls forming this so-called '*Saline Series*' closely resembles that of the Eocene Series of Kohat^{383 413} (see below under 'Tertiary'), though the supposed discovery of Eocene foraminifera^{239 267 327} in the marl of the Salt Range is believed to be mistaken.

The Purple Sandstone is from 250 to 450 ft. thick, and is unfossiliferous, except for some obscure 'fucoid' markings. It is succeeded conformably by the fossiliferous dark shales known as the *Neobolus beds*, 100 ft. thick. Interbedded with the shales are glauconitic sandstones and dolomitic sandstones in thin layers, and the beds are divided into several zones by means of their fossils²⁵, which include the trilobites *Eedlichia* (allied to *Olenellus*) and *Conocephalites*, together with the pteropod *Hyolithes wyneei* and certain peculiar brachiopods (*Neobolus ivarthi* and species of *Lakhmina*, *Schizopholis*, etc.). From the affinities of *Eedlichia* and the associated organisms the beds were referred to the Lower Cambrian^{24a}. But it seems that some part of the *Neobolus* beds belong to the Middle Cambrian, because of the recent²⁵⁷ discovery in them of the trilobite genus *Ptychoparia*. The overlying *Magnesian Sandstone Group* contains only a few fossils. It is about 250 ft. thick, and passes up gradually into the so-called *Salt-pseudomorph zone*, 450 ft. thick, which consists of flaggy dolomites and sandstones, with interbedded shales and bright red clays, and contains pseudomorphs in sand of crystals of salt, together with some fucoid markings. The next higher beds in the Salt Range are of Permo-Carboniferous age.

In the Trans-Indus region of Kohat⁴¹³, west of the Salt Range, rocks resembling the Purple Sandstone are present, while the higher beds consist of gypsum, dolomite, and bituminous shales, all apparently unfossiliferous. It is doubtful if these do not correspond to the Saline Series⁴¹⁴ of the Salt Range.

CENTRAL HIMALAYAS¹⁴.—In Spiti, Niti, and Rupshu in the Central Himalayas there is a great series of sedimentary rocks, which are involved in the Himalayan folds, and in their lower part are unfossiliferous, but the upper part contains Cambrian fossils and follows on in an apparently conformable sequence, the whole being known as the *Haimanta System*¹³. The lower division, as above mentioned, may belong to the Puranas, but in Spiti this lower part (though represented in *Niti* by a great thickness of conglomerates and quartzites) is absent, and the oldest sedimentary rocks are here referred to the Middle division of the Haimantas. This division in Spiti consists of 2000-3000 ft. of soft ferruginous clay-slates with bands of grey and purple quartzite. The beds are folded, and in places metamorphosed, and here and there have been crushed and altered into garnetiferous mica-schist, kyanite, and staurolite-schist. None has yielded any fossils. Above them comes a series (*Upper Haimantas*) of bright red and black unfossiliferous slates, 1000 ft. thick, marking this horizon distinctly, and they are succeeded by grey or green micaceous quartzites, thin foliated slates, and narrow bands of dolomitic limestones, which are fossiliferous^{14 25} on certain horizons, and include representatives of Lower, Middle, and probably Upper Cambrian horizons. There are five distinct trilobitic zones which have been recognised on the Parahio River, each containing a special fauna. The genus *Redlichia* occurs in micaceous sandy slates at the base, the middle zones contain *Ptychoparia*, *Oryctocephalus*, *Microdiscus*, *Zacanthoides*, and the brachiopods *Acrotreta*, *Lingulella*, etc.; the genus *Dikelocephalus* probably occurs in the uppermost beds²⁶.

The Haimanta System is succeeded in Spiti by a great conglomerate forming the base of the *Muth System* (see below).

The fauna of these Cambrian beds has remarkable affinities with that of the Pacific bio-geographical province of North America, and is distinct from that of Western Europe¹⁸⁸, but this has been questioned⁴⁴⁵.

In north-western **Kashmir**^{30 224} the Cambrian is represented by a series of various lithological types of sedimentary rocks, and some part of the Dogra slates with worm tracks may be Lower Cambrian. But the chief fossiliferous beds^{223 228} are shales of Middle and Upper Cambrian age, containing many genera of trilobites, including *Agnostus*, *Ptychoparia*, *Conocoryphe*, *Tonkinella*, *Anonbocare*, *Dolichometapus*, *Solenopleura*, etc., but none of the Spiti species have been recognised.

2. Ordovician.—It is only in the Central Himalayas, Kashmir²²⁴, and Burma that fossiliferous Ordovician rocks have so far been recognised.

CENTRAL HIMALAYAS.—In Spiti¹⁴ there is a conglomerate following on the fossiliferous Cambrian Haimanta beds, as above described, and it is succeeded by quartzites and sandstones and then by a conspicuous red quartzite 1500 ft. thick, which is gradually replaced by flaggy beds, shales, and limestones containing Ordovician fossils (*Cheirurus*, *Illæus*, *Calymene*, *Asaphus*, *Orthis*, *Strophomena*)²⁷, with a total thickness of about 500 ft. These beds form the lower part of the *Muth System* (see below).

Farther to the east in the Niti area, a rich Ordovician fauna, first described by Salter, has been discovered, containing many of the same species as in

¹ The unfossiliferous section of the ill-defined Haimanta system is believed by Auden to correspond in the main to the Simla Slates,—E. H. P.

Spiti, and undoubtedly the beds are a continuation of those in that district²⁷. In Kumaon there are similar fossiliferous beds.

In Kashmir^{80 228 224} there is some evidence for the presence of Ordovician rocks in the occurrence of a species of *Orthis* in ferruginous sandstones at Marhaum, together with fragments of other brachiopods and trilobites.

BURMA.—In the Northern Shan States there is an extensive development of Ordovician beds known as the *Naungkangyi* and *Hwe Mawng Series*¹⁸. These consist of shales, mudstones, and limestones, the latter occurring apparently in lenticular masses. The beds contain a rich fauna^{28 29} of cystideans (*Helio-crinus*, *Protocrinus*, *Aristocystis*, etc.), brachiopods (*Orthis*, *Rafinesquina*, *Plectambonites*), trilobites (*Asaphus*, *Ogygites*, *Pterygomotopus*, *Ampyx*, *Harpes*, *Retnopleurides*, *Pliomera*, *Calymene*), etc., the whole assemblage having a North European faunal type, but the species are mostly local¹⁸⁸. The Naungkangyi Series is divided into a Lower and Upper Stage, but the faunistic distinction is not strongly marked. The Hwe-Mawng Series has a slightly different fauna. In the Southern Shan States the Naungkangyi beds are also present with certain local lithological and faunistic differences^{189 202 210 211 238}. The fauna of the Naungkangyi beds is of Middle and Upper Ordovician type, but there is some evidence that Lower Ordovician horizons are also locally represented by the Mawson siltstones²³⁸. In the Bawdwin^{106 183} area a series of unfossiliferous sandstones and quartzites overlies the ore-bearing series of pre-Cambrian (?) rhyolites, and pass below the Naungkangyi shales, but their age is uncertain, though it is probable they are Vindhyan.

3. Silurian.

CENTRAL HIMALAYAS.—In Spiti^{14 27} the top of the Ordovician passes up into siliceous limestones less than 100 ft. thick, containing corals and the typical *Pentamerus dulongus*; capping these beds is a great white unfossiliferous quartzite, the *Muth Quartzite*, of great thickness, probably in part of Devonian age, and extending over a wide area. The combined Ordovician and Silurian succession of beds has been termed in this region the *Muth System*, and it seems to extend east and west to the Central Himalayas.

KASHMIR.—In south-eastern Kashmir⁸⁰ there is a thick series of unfossiliferous slates, thin limestones, quartzites, and greywackes, partly of Ordovician and partly of Cambrian age, which form a great anticlinal arch. In many parts the beds are altered and sheared. Overlying them conformably there are fossiliferous Silurian beds consisting of calcareous sandy shales about 100 ft. thick, yielding a small Wenlock fauna of European character³¹, including species of *Calymene*, *Illcenus*, *Encrinurus*, *Acidaspis*, *Orthis*, *Triplegia*, *Strophomena*, *Camarotoechia*, etc. In north-western Kashmir²²⁴ beds of this age have yielded no fossils.

BURMA.—In the Northern Shan States¹⁸ it is believed that the thin limestone containing *Camarocrinus*^{28 268} succeeds the Ordovician beds, but its true stratigraphical position is somewhat uncertain, though it is probably of Silurian age. The earliest Silurian beds, with a well-defined fauna, are calcareous shales and mudstones referable to the Llandovery and yielding characteristic graptolites and other fossils^{28 29}. The graptolites include *Mesograptus modestus*, *Orthograptus vesiculosus*, *Climacograptus medius*, *Moriograptus tenuis*, *M. concinnus*, *M. gregarius* and *M. priodon*, and point to the existence of several horizons. The other fossils include species of *Acidaspis*, *Dalmanites*, *Stropheodonta*, *Orthis*, etc.

These beds have been termed the *Panghsapye beds*, and are followed by red, yellow, and white sandstones known as the *Namhsim Sandstones*, which

have yielded *Orthis bilobites*, *Pentamerus*, *Schuchertella*, *Encrinurus*, *Phacops*, *Calymene*, etc., several of the species occurring also in the European Wenlock and others being closely allied. The *Konghsa Marls*, or Upper Namhsim beds, containing trilobites, etc., seem to be only a different lithological facies of the same general age.

Above the Namhsim beds come the *Zebingyi beds*^{28 226}, consisting of black flaggy limestones and shales yielding *Monograptus riccortensis*, *Atrypa marginalis*, *Orthoceras* sp., a *Phacops* (of the Hercynian type), and crowds of *Tentaculites elegans*. This fauna seems to have affinities with the Bohemian Lower Devonian, except for the occurrence of *Monograptus*¹⁸, but apparently several horizons must be present, though they have not as yet been differentiated.

In the Southern Shan States there are graptolitic shales^{202 210 211 288} and mudstones of Valentian age, similar to those in the Northern Shan States; other higher Silurian beds occur, yielding trilobites and brachiopods. The Zebingyi beds are also represented, and there is a peculiar little fauna at Loilem which may be of Lower Devonian age.

4. Devonian.

CENTRAL HIMALAYAS.—In Spiti and Bashahr in the Central Himalayas there is a series of beds overlying the Muth Quartzite without a break, known as the *Kanawar System*, and containing brachiopods and corals in the basal grey limestone, 300-400 ft. thick, which forms part of the so-called Lipak Series. These apparently indicate a Middle Devonian age, for they include *Orihothetes umbraculum*, *Atrypa aspera*, etc.³².

CHITRAL.—Lower Devonian fossils have been recognised in a black limestone in Chitral³², and there is said to be a conformable sequence from the Lower Devonian to the Carboniferous Fusulina Limestone. But the chief Devonian beds in Chitral, and farther north in the Pamirs, are referable to the Upper Devonian^{33 229 230}, and consist of dark massive or flaggy limestones with a rich typical Upper Devonian fauna resembling that of the Urals, and including *Spirifer murchisonianus*, *Sp. verneuili*, *Atrypa aspera*, *Douvillina dutertrii*, and species allied to *JRhynchonella cuboides*, *Athyris concentrica*, etc., together with many corals²²⁹. Two or more horizons, each with a well-marked fauna, are represented in this region. There is an American element in the upper fauna, as noted elsewhere in areas farther to the north.

KASHMIR.—The Devonian in south-eastern Kashmir⁸⁷¹ may be represented by part of the Muth quartzite which has here the same relations to the Silurian as in Spiti and Kumaon. But it is unfossiliferous.

BURMA.—In Burma, apart from the transitional Zebingyi beds, we find a great development of limestone (the Plateau Limestone), part of which, at any rate, belongs to the Middle Devonian¹⁸, as proved by the fossils, for at Padaukpin in the Northern Shan States the limestone has yielded a rich fauna⁸⁴ characteristic of the Calceola Stage with a typical Rhenish facies, many of the species being identical and including *Calceola sandalina*, *Stropheodonta interstrialis*, *Orthothetes umbraculum*, *Cyrtina heteroclita*, *Pentamerus brevirostris*, and many bryozoa. An Upper Devonian fauna²²⁶ also is found in a limestone in the vicinity. Recently the Devonian fauna of Padaukpin with characteristic brachiopods has been found in the Plateau Limestone of the Southern Shan States.

A series of shales at Wetwin contains a peculiar fauna with many lamelli-branohs, the genus *Paæoneilo* being particularly abundant; it includes also species of *Chonetes*, *Echinocaris*, *Fenestella*, etc. It seems more allied to

the Naples fauna of the Upper Devonian of New York than to any known Asiatic or European assemblage. Apparently it is a band occurring amongst the limestones of the Plateau, but its precise relations to the Padaukpin beds are not known.

It is certain that only part of the Plateau Limestone of the Northern and Southern Shan States is of Devonian age, for a large portion is now proved by the fossils to be referable to the Permo-Carboniferous (see below). These limestones extend northwards into Yunnan and China, eastwards across the Salween, and southwards into the Southern Shan States and Tenasserim. LaTouche¹⁸ estimates their total original thickness in the Northern Shan States to have been probably not less than 3000 ft.

5. Carboniferous.

CENTRAL HIMALAYAS.—In Bashahr¹⁴ the Devonian limestones pass up into Lower Carboniferous Limestones containing a typical European fauna of that period. The same beds occur in Kanawar and Spiti. The faunas from these beds have been described chiefly by Diener^{50 51}, but Hayden³⁶⁰ has added to the lists of species. The upper part of the so-called *Lipak Series* in Spiti¹⁴ (part of which, as above mentioned, belongs to the Devonian), and the whole of the succeeding *Po Series* are referable to the Carboniferous. The Carboniferous portion of the *Lipak Series* (correlated with the European Lower Carboniferous) is mainly calcareous and shaly, with some beds of gypsum; it contains numerous brachiopods (*Productus*, *Syringothyris*), mollusca, and trilobites (*Phillipsia*), several of the species being identical with European forms of this age. The overlying *Po Series* consists of dark shales and quartzites, and has a Culm-like lower portion containing plant-remains⁴¹⁹ (including *Mkacopteris ovata*), and an upper portion with shale-bands containing marine fossils, including many brachiopods, but especially bryozoa, the genus *Fenestella* being particularly abundant so that they are called the *Fenestella Shales*⁵¹. The affinities of the fauna indicate a Middle or Upper Carboniferous age³⁶⁰. These shales pass upwards into a conglomerate containing fragments of the *Po* quartzites, *Lipak* limestones, and older beds, and marking the end of the Carboniferous period as well as of the Dravidian era, for it points to the interval of great erosion which ushered in the Permian and the Aryan era.

-KASHMIR.—In south-eastern Kashmir^{30 50 51 371} where no fossiliferous Devonian has been detected, the Carboniferous beds of the *Lipak Series* directly overlie the quartzite of the *Muth Series*, and consist of a limestone containing *Syringothyris cuspidata*, *Prodtctus*, *Chonetes*, *Phillipsia*, etc., which is known as the *Syringothyris Limestone*. Then follow some unfossiliferous limestones, and they are succeeded by the *Fenestella Shales* containing many bryozoa, especially *Fenestella*, together with *Spirifer*, *Prodwus*, *Strophalosia*, and other brachiopods, and corresponding partly to the *Po Series* of Spiti, Kumaon, and other parts of the Central Himalayas. These *Fenestella* beds, which here consist mainly of quartzites with only thin beds of shale intercalated, are about 2000 ft. thick, and their fauna^{50 51} is peculiar, many of the species being unknown elsewhere.

Above these beds comes the great Panjal conglomerate and volcanic beds, which are probably for the most part of Permian age and belong to the base of Holland's Aryan Group (see below). In north-western Kashmir²²⁴ the fossiliferous Carboniferous is absent.

CHITRAL.—The Carboniferous in Chitral⁸⁶⁰ is represented by the Upper Carboniferous *Fusulina Limestone* and *Bellerophon* beds, which extend into

the Pamirs and contain a rich marine fauna of brachiopods, bryozoa, and few mollusca⁸⁵⁸.

In connection with the structure of the Himalayas it may here be mentioned that Mount Everest^{264 403} is partly composed of limestone about 2000 ft. thick, which is supposed to be of Carboniferous age. Below it is the 'Pelitic Series'^{394 403} of shales and slates, 4000 ft. thick, of unknown (? Pre-Cambrian) age. The Mount Everest limestones form the summit and are succeeded by Permian (Productus) limestones.

BURMA.—In the Northern Shan States¹⁸ there is apparently no break between the Dravidian and Aryan eras, the deposition of calcareous marine sediments having gone on uninterruptedly from Devonian into Carboniferous and Permian times. But whether there is an undetected unconformity in the apparently unbroken and lithologically uniform Plateau Limestone remains to be proved. So far no true Lower Carboniferous fauna like that of the Central Himalayas has been found in Burma, and those fossiliferous limestones, which are of later date than Devonian, contain the fauna of the Permian Productus beds of the Salt Range and Central Himalayas (see below). As previously remarked, the *Mergui Series*^{190 199 241} in southern Burma and the coastal islands has been usually placed in the Pre-Cambrian, but it may²⁶¹ include Carboniferous or Devonian beds. The Mergui Series consists of argillites, greywackes, and agglomerates, and is strongly folded, the beds usually having high dips and being often metamorphosed. The agglomerates are of volcanic origin. No fossils have been found in these beds, and their age is an open question¹⁹⁹. The *Moulmein Limestone Series* overlies the Mergui Series, in one place conformably, and has yielded a few Carboniferous fossils, according to Noetling⁴⁴. The Moulmein limestone shows a difference¹⁹⁹ in folding and metamorphism.

GROUP 4—ARYAN ERA

(i) EXTRA-PENINSULAR AREA.

(a) **Permian and Trias.**—At the close of the Dravidian era great changes took place in the physical geography of much of central Asia, and extensive orogenic movements occurred. In most parts a period of erosion then followed, and the land areas which had been formed suffered extensive denudation before the sea again advanced and covered the subsiding regions. The thick series of marine strata in the Himalayan area, which was laid down in the subsequent submergence and embraces the whole of the Permian period and most of the Mesozoic era of Europe, commences with a widespread conglomerate. An immense mid-Eurasian ocean ('Tethys') was spread over much of central Asia, and covered the Central Himalayas and Burma; it also sent an arm down into the Punjab, and to the north-west must have extended over a large area of undetermined extent, probably connecting with the Mediterranean in Europe. The present line of snowy peaks in the Central Himalayas seems to have formed the southern shore-line of this ocean, the marine beds deposited during this era being mostly found in a zone to the north of them. The continent of Gondwanaland, of which the present Peninsular area forms a remnant, lay to the south of this great sea.

The most complete succession of conformable strata is preserved in the Central Himalayas, where marine conditions seem to have continued onwardly uninterruptedly from Dravidian into Aryan times, so that from the base of the Permian to the Cretaceous there is a thickness of 7000 ft. of strata in unbroken sequence. This central region is exceptional in not having a great unconformity apparent everywhere at the base, though the Tethys was undoubtedly

transgressive over all the older Palaeozoic strata. A conglomerate and sandstone are, however, present in Spiti, indicating, at any rate, local shallow water conditions in the early stages.

On the other hand, in Peninsular India (see below) the same long period of time is represented by the accumulation of great masses of fluvatile or sub-aerial sandstones (Gondwana System) associated with coal-seams, and finally covered by enormous lava-flows, but there is no evidence of marine conditions, except in a few places near the coast. In this terrestrial area there is a peculiar boulder-bed³³⁹ of great interest at the base of this fresh-water series (see below). But before the deposition of these terrestrial and fresh-water beds there was faulting or warping of the surface of the much-worn ancient platform breaking up portions into separate blocks and depressing others so as to form troughs or basins in which the sediments afterwards accumulated. Only one local marine incursion has so far been discovered, and it only lasted a short time. The fossiliferous deposit^{194 194a} which indicates it occurs in the Umaria coal-field^{194 249} of Rewah (see below).

SALT RANGE^{227 302}.—The marine succession has been closely studied in the Salt Range^{24 35 168}, so that we are better acquainted with the strata, and particularly the fossils, of this district than with those of most other areas in India.

The Permian is here mainly represented by the calcareous beds known as the *Productus Limestones* from the abundance of the brachiopod genus of that name⁴⁷⁸. In other parts of India the homotaxially partly equivalent beds have been frequently termed the 'Anthracolithic' Formation, as they include beds which are referable to the Upper Carboniferous. There is also a complete passage up from Permian into Triassic formations, and there is some difficulty in drawing the line between them, apart from their fossil contents.

There is in the Salt Range, below the *Productus Limestones*, a series of chiefly arenaceous beds, generally known as the *Speckled Sandstone Series*²²⁷, with a basal boulder-bed or tillite of peculiar interest resting unconformably on the Cambrian. This boulder-bed is known as the *Talchir Stage*, from its great development at the base of the Gondwana System in Peninsular India (see below), and is composed of a fine-grained greenish sandy or shaly matrix, in which are imbedded sub-angular, faceted, and striated boulders of all sizes, consisting of quartzites, slates, and various crystalline rocks, including Vin-dhyān feisites from the Aravalli Range 760 miles to the south²²⁷. Occasionally beds of sand or conglomerate are found interstratified and splitting up the boulder bed. The general character of the deposit, the striation and faceting of the boulders, the nature of the matrix, and the absence of stratification and sorting, as well as the occasionally striated surface of the solid rock on which the bed rests (as on the Penganga River in Central India), point unmistakably to a glacial origin³³⁹. The beds immediately associated with and conformably overlying the boulder-bed contain an Upper Carboniferous or Permo-Carboniferous peculiar marine fauna^{181 185 187 193}, including many species found in similarly placed beds in Australia (q.v.), where they are associated also with a boulder-bed having identical characters; some of the same species have recently been found in the Dwyka Conglomerate Series of South-West Africa. The identical species occurring in India and Australia (q.v.) include the mollusca *Eurydesma globosum*, *E. cordatum*, *Conularia Icevigata*, *C. tenuistriata*, *Pleurotomaria nuda*, and the brachiopod *Spirifer (Martiniopsis) darwini*¹¹¹.

The boulder-bed in the Salt Range^{168 227} varies from 20 to 150 ft. in thickness, and the associated olive sandstones, clays, red shales, and red and purple sandstones, which overlie it and contain the above fauna in their lower portion, possess a thickness of 400-500 ft. It has been proposed by

Gee²⁷⁸ to substitute the name *Nilawan Series* for 'Speckled Sandstone', because the Speckled Sandstone is only one stage in the series of beds below the Permian *Productus* Limestone. The succession of this series in the Salt Range is as follows in descending order:—

Lavender Clay Stage.
Speckled Sandstone Stage.
Conularia beds.
Talchir Conglomerates.

The whole series has been termed the Punjabian. Boulder-beds like the Talchir Conglomerate of the Salt Range, and containing likewise glacial boulders of Malani rhyolites together with other rocks, are known in Rajputana, and in one place *roches moutonnees* occur. It seems that the centre from which the glaciers spread was in the Aravalli area. There is no apparent break in the stratigraphical succession between these beds, which have a peculiar fauna, and the conformably overlying calcareous Permian *Productus* Series which succeeds them. There is considerable difference of opinion as to whether this and equivalent boulder-beds in India should be regarded as marking the top of the Carboniferous or the base of the Permian. At any rate the fauna of the beds of the Nilawan Series immediately above it are peculiar and unlike typical Upper Carboniferous or Lower Permian assemblages of fossils. But there is no break in the stratigraphical succession in the Salt Range, the only unconformity being below the boulder (Talchir) bed, and for this reason it seems more suitable to group it with the Permian.

In the Simla area the *Blaini Conglomerate*^{137 184 242}, below which there is a great unconformity, is now, as above mentioned, generally regarded as corresponding to this Talchir bed, and it is followed by a magnesian limestone¹⁸⁴, the Blaini limestone, and then by the Infra-Krol beds of shales and lenticular beds of quartzite and sandstone. The *Krol Series*^{181 242} appears to succeed, consisting of limestones and shales, but its age is doubtful; as mentioned previously, it was by some held to be of Pre-Cambrian age, but more recent work by Auden should seem to place it straddling the Upper Palaeozoic and Lower Mesozoic.

In Kashmir^{185 193} arenaceous beds, associated closely with typical 'Agglomeratic Slate,' occur near Srinagar (see below), containing many of the same lamellibranchs and other fossils, and may be regarded as of the same age as the Nilawan Series.

The immense geographical extent of similar boulder-beds at this horizon throughout the southern hemisphere indicates the existence of widespread uniform conditions for their formation, and since the peculiar characters of the beds clearly point to the action of ice it is generally held that they indicate the occurrence of a glacial period^{130 168 277 280} affecting the whole southern hemisphere.

The subsequent gradual submergence of the Salt Range area beneath the waters of the Tethys led to the accumulation of the purely marine *Productus* Limestones. These are about 800 ft. thick, and are divided into the following three stages, comprising many palaeontological zones.

The Lower *Productus* Limestones (or Amb Stage), which conformably overlies the Speckled Sandstone, are sandy and carbonaceous in the east, but more calcareous towards the west. The fossils^{35 258 272 473} show affinities with the Upper Carboniferous (*Fusulina* Limestones) of the Carnic Alps and Russia, and there are also species of the higher Artinskian Stage (Permo-Carboniferous or of younger European stages. Species of *Productus* and *Spirifer* are particularly abundant, and the peculiar brachiopod *Richthofenia*, which also occurs on the same horizon in China, is noticeable. Near the base of the Lower *Productus*

Limestone in the Warcha Valley²²⁷ a thin band of shale has yielded characteristic members of the flora of the Lower Gondwana beds of the Peninsula (see below), including *Gangamopteris cyclopteroides*, *G. major*, *O. kashmirensis*, and *Glossopteris indica*, all of them species occurring in corresponding beds in the Lower Gondwanas of the Peninsula and Kashmir. A fresh-water lamellibranch fauna²⁷⁸, including species of *Palæomutela*, *Palæanodonta*, *Carbonicola*, and *Anthracomya*, with some minute ostracods and fish-scales, has recently been found in black carbonaceous shales about 25 ft. above the boulder bed in the Nilawan (Speckled Sandstone) Series near Kathwai rest-house in the Shahpur district. These fossils are associated with Lower Gondwana plants (*Glossopteris*, *Gangamopteris*, etc.), and are therefore on a slightly lower horizon than the plant-remains in the Warcha section. The supposed mixture of Lower Carboniferous species with the many peculiar species of Permian type which Waagen³⁵ described, appears to have been due partly to erroneous identification; the fauna is now considered to have an almost pure Permian character²⁷², and to be closely allied to faunas of this age in other parts of the Tethys region. The foraminifera, according to Dunbar²⁷⁵, establish the Permian age of the Lower Productus Limestone. There is a complete absence of those species which are found in the Speckled Sandstone and glacial beds.

The Middle division of the Productus Limestone, including the Virgal Stage, is almost 200-300 ft. thick, and is characterised by a slightly different assemblage of fossils. It possesses three palæontological zones, the lowest of which is marked by the genus *Fusulina*, the next by the strange brachiopod *Lyttonia nobilis*, and the upper one by the cephalopod *Xenodiscus carbonariue*; the appearance of ammonites shows the Triassic affinities of the upper zone, but mostly typical Permian brachiopods and corals occur in it. Lithologically this division consists of blue and grey limestones with dolomitic and marly layers, and flint and chert concretions are common.

The Upper Productus Limestones including the Chidru Stage at the top are characterised by ammonites of remarkable types, such as *Cyclolobus oWhami* and *Medlicottia wyneii*. The ammonites have a certain Triassic character, but the topmost zone of the formation is marked by a species of *Bellerophon* (*Euphemus indicus*). This division is thinner than the Middle one, and more arenaceous in character, sandstones and carbonaceous shales predominating. The faunistic relations of the Middle to the Upper Productus Limestones are much closer than those of the Lower to the Middle.

The type of fauna contained in the Productus Limestones is very widespread, extending from the Urals to Japan across all Eurasia^{126 272 473}, but with local peculiarities.

Since there is here a gradual passage up into beds with an essentially Triassic fauna (see below) without any physical break, the divisional line between the Palæozoic and Mesozoic, and between the Permian and Trias, has not been drawn at the same level by every geologist, and there is no universal agreement as to the correlation of the beds with the European scale. Nor are the three divisions of the Productus Limestone clearly separable into definite stages by the brachiopods and mollusca^{277-280 473}.

The Triassic beds of the Salt Range, which overlies the Chidru Stage conformably, are characterised by the cephalopod genus *Ceratites*, and the whole series is frequently known as the *Ceratites Formation* or Scythian Stage. It is lithologically divisible into four stages known (in descending order) as the Upper Ceratite Limestones, Ceratite Sandstones, Ceratite Marls, and Lower Ceratite Limestones. The beds consist of arenaceous limestones, oolitic sandstones, and marls. Five successive palæontological zones are recognised in these beds, marked by species of ammonites of the genera *Celtites*, *Prionolobus*, *Koninckites*, *Flemingites*, and *Stephanites*. A great variety of other

genera of ammonites is also present, as well as mollusca and brachiopods. The whole fauna is quite distinct from that of the Upper Productus Limestone¹⁶⁷. The total thickness of this stage in the Salt Range is about 200 ft., and it is regarded as mainly approximately equivalent to the Lower Trias of Europe, but the upper beds correspond to the lower part of the Middle Trias of the Himalayas. Plant-remains of Triassic age have also been recorded from the Salt Range⁴⁷⁹. All the younger Triassic beds present in the fuller development of the Trias in the Himalayas are wanting in the Salt Range.

CENTRAL HIMALAYAS.—In the Simla area it has been suggested²⁴² that the *Infra-Krol* and *Krol series*¹⁸⁴¹ of limestones, though apparently unfossiliferous, are largely of Productus Limestone age, because the Blaini Conglomerate probably represents the Talchir boulder-bed. In the Central Himalayas the Carboniferous-to-Trias^{14 36} exhibits a thick and unique succession of conformable strata of a special type. The lower part is known as the *Ruling System*¹⁰, and consists at the base of a conglomerate (but not a boulder-bed) resting in places on the Carboniferous Fenestella Shales of the Po Series, or on various horizons from the Silurian to the Carboniferous. This conglomerate is succeeded by a calcareous sandstone containing the fauna of the Lower Productus Limestone of the Salt Range, and it is followed by the conspicuous *Productus* (Kuling) *Shales*, containing many of the characteristic Salt Range fossils of the higher Productus Limestones. These black siliceous friable shales, 100-200 ft. thick, are remarkably constant from Kashmir to Nepal, and pass up into more calcareous and deeper-water deposits, characterised by different genera of ammonites. There is no physical break in this succession. The lowest of these deposits (consisting of shales and limestones) is known as the *Otoceras Beds*^{186 282}, which are generally correlated with the lower part of the Ceratite beds of the Salt Range. Diener³⁶ positively regards them as Lower Triassic, and not as Permian. The characteristic species is *O. woodwardi*. In Spiti^{14 238} the *Ophiceras Beds* follow, and then the *Meekoceras* and *Hedenstrœmia Beds*. But the whole Lower Trias is thin (50 ft.) compared with the Middle or Upper divisions. The higher Triassic beds which are not represented in the Salt Range are here developed, for the Middle Trias is present, and is composed chiefly of 400 ft. of limestones containing the Muschelkalk fauna, and characterised by abundant species of *Ceratites*, *Sibirites*, *Ptychites*, etc. The brachiopod *Spiriferina stracheyi* marks the lower beds, and the lamelli-branch *Daonella lommeli* the upper beds. The Upper Trias is much thicker (2800 ft.), and consists of an enormous succession of limestones and dolomites with some shales and sandstones belonging to the Carnio and Noric Stages^{282 283}, and having the *Halobia Beds* near the base with the *Tropites Beds* above. Still higher in the series are the *Juvavites Beds* of Spiti, and the *Halorites Beds* of Kumaon containing a host of genera and species of ammonites⁴⁰, including *Pinacoceras*. Lastly come the *Monotis salinaria Shales* and quartzites containing *Spiriferwia griesbachi*^{39a 40a 282}. The rocks are rich in fossils, and remain uniform in character over immense distances, forming the great scarps of the plateau of Tibet, and extending along the whole northern boundary of the Himalayas.

All those Triassic beds, from the *Otoceras* beds to the topmost quartzites, are sometimes grouped together under the name *Lilang System*¹⁰.

In SPITI^{14 36} and NEPAL there are still later beds referred to the *Bhœtic* consisting of massive limestones with the fossil bivalve *Megalodon*, and everywhere in the Himalayas the Upper Noric beds pass up through beds of doubtful correlation into Middle Jurassic limestones.

In the NORTH-WEST FRONTIER PROVINCE of India (e.g. in Bannu) we find the Permian basal boulder-bed present, together with a closely similar Permo-Triassic succession overlying it; in Hazara^{37 224} there is a specially complete

stratigraphical sequence extending from the Trias (with rhyolitic lavas at the base), followed by fossiliferous limestones containing an Upper Triassic fauna (the Lower and Middle Trias being absent), to the Nummulitic formation of the Eocene. The whole succession from Permian to Eocene can be well traced on Mount Sirban. In the Attock district²²² similar Upper Triassic limestones are found. In Gilgit the beds are much altered by post-Triassic igneous intrusions¹⁹¹.

BALUCHISTAN.—In Baluchistan (Quetta district) the Lower and Middle Trias are missing, and the Upper Trias rests directly on Fusulina Limestones. The *Monotis Shales* are largely developed in some parts, with typical lamellibranchs. The rocks are several thousand feet thick, and limestones are subordinate to shales and slates.

KASHMIR.—In Kashmir^{80 224 251} there is a most interesting and important development of the lower part of the strata of the Aryan era, for it supplies a valuable clue to the relations between the marine beds of the Himalayas and the Gondwana fresh-water series of the Peninsular area, and helps to fix the age of the latter⁴⁸⁵⁰⁶¹.

Resting unconformably on the Fenestella Shales of the Carboniferous is the *Panjal Volcanic Series*^{30 224}, several thousand feet in thickness, and composed partly of basic lavas in sheets 1-20 ft. thick, and partly of slates, but especially of a remarkable type of rock known as the '*Agglomeratic Slate*'^{193 251}—a dark grey fine deposit containing angular fragments of quartz, felspar, slate, quartzite, porphyry, pegmatite, and granite, from the size of a pea to that of a piece several inches in diameter. No striation or faceting has been noticed on any of these fragments. But a glacial conglomerate²⁸⁷, with scratched and faceted boulders similar to that in the Salt Range, has recently been found interbedded with the Panjal Volcanic Series. The matrix of the Agglomeratic Slate, on the other hand, is found to be a fine volcanic tuff²⁵¹, and we may regard this rock as having been formed by submarine explosive volcanic action. In one of the arenaceous beds of the Volcanic Series near Srinagar a marine fauna^{185 193}, closely allied to that occurring in the Speckled Sandstone of the Salt Range and containing several of the same species, has been recently found. It includes some brachiopods (*Productus*, *Syringothyris*, etc.) and many lamellibranchs (*Eurydesma*, *Astartila*, etc.), and resembles the faunas of the lowest Permian or Upper Carboniferous of eastern Australia, associated with evidence of similar glacial conditions and boulder beds.

Overlying the Panjal Volcanic Series⁴⁸ conformably are fresh-water black shales and sandstones containing the plants *Gangamopteris* and *Glossopteris*, being in fact the flora of the Lower Gondwana formation of Peninsular India. The vertebrate *Actinodon* of the same formation has been found in the volcanic tuffs associated with these plant-remains. These beds are about 400 ft. thick, and have at their base a thin conglomerate. But the earthy massive sandstones at the top of the series become calcareous, and pass up into impure limestones, massive marine limestones, and shales, known collectively as the *Zewan Beds* which contain the bryozoan *Protoretapora ampla* and many species of *Productus*, *Athyris*, *Spirifer*, *Camarophoria*, and *Lyttonia*, with the ammonites *Xenaspis* and *Popanoceras*. These beds are undoubtedly referable to the Middle or Upper Productus Limestone Series of Permian age^{60 57}. The fauna bears close affinities with that of the Productus Shales of the Central Himalayas. Inliers of the Productus Limestones have been discovered in Jammu⁸²².

Conformably succeeding them in south-eastern Kashmir come **Lower Triassic limestones, 300 ft. thick, containing *Ophiceras*, *Meehoceras*⁴⁰, etc.,**

but the *Otoceras* beds seem wanting. The higher Triassic beds show a very complete and thick sequence comparable to that of the Central Himalayas, and are composed of about 900 ft. of limestones and shales rich in characteristic Middle Triassic fossils. The Upper Trias (Carnic and Noric Stages) follows on in the form of massive limestones, many thousands of feet thick, mostly unfossiliferous, but containing a few lamellibranchs, *Spiriferina*, etc.

In north-western Kashmir^{224 871} the fossiliferous limestone facies of the Lower and Middle Trias appears to be absent. The Panjal Trap Series, 7000 ft. thick, is followed here by Upper Triassic beds containing the lamelli-branch *Megalodon*, etc. Representatives of the Agglomeratic Slate and Panjal Series are found in Hazara²²⁴, and the *Kioto Limestone*, containing *Megalodon*, in Spiti, Byans, Kashmir, and the Attock²²² district is now referred to the Trias. In the Karakoram Range fossiliferous Permo-Carboniferous limestones³⁹⁹ and shales resembling those in Kashmir are also developed.

FAUNISTIC CHARACTERS.—The whole Himalayan Triassic zoo-geographical province⁸⁶ extends from Herat through the Himalayas, southern China, the Malay region, and the East Indies into New Caledonia. The successive faunas were distributed uniformly, and had the same vertical range. Cephalopod-bearing beds are conspicuous in the succession. The characters of the fauna and the development of the beds in this province are in strong contrast with those of the Mediterranean area, and of the Salt Range. The Triassic faunas of the Himalayas have been specially described by Diener^{29a 40 40a}, Mojsisovics²⁸³, and Bittner²⁸² in a series of monographs in the *Palæontologia Indica*. Middlemiss³⁰ and Wadia²²⁴ have given detailed descriptions of the succession of these beds in the Kashmir area.

In the region of the so-called 'exotic blocks'^{36 64} in Malla Johar^{39 40}, and near 'Chitichun No. 1' on the Tibetan frontier, the Trias is of small thickness, and consists chiefly of red limestones and marble, much resembling that of Hallstatt, while the beds referred to the Carnic Stage agree remarkably with those of the Mediterranean region. This facies is quite distinct from that of the Central Himalayas. Overlying the Carboniferous (?) Mount Everest limestones⁴⁰⁸ there come on the northern side of this mountain representatives of the Productus Limestones (Permian) containing typical brachiopods²⁸¹. These beds have been termed the *Lachi Series* and underlie Jurassic (Spiti ?) shales. In northern Sikkim the Lachi Series²⁶⁴ consists of shales, quartzites, and sandstones, and on the east side of the Lachi ridge a series of limestones has yielded a rich Triassic fauna of ammonites, brachiopods, and lamelli-branches^{281 357}. These beds belong to the Tibetan belt of the Himalayas north of the crystalline axis. The isolated position of these 'exotic blocks' appears to be due to earth-movements followed by erosion.

ASSAM AND BURMA.—In the Eastern Himalayas (Sikkim²⁸¹) and Assam beds corresponding with the Productus Limestones are known, with marine fossils⁴⁸¹. In the Northern and Southern Shan States of Burma there is a great calcareous development of the Middle Productus Limestones containing the typical fauna^{148 228 806}, and forming the upper part of the so-called *Plateau Limestones*, which extend far to the east and north into adjoining countries. In the Northern Shan States the typical Productus Limestone ammonoid *Xenaspis carbonaria* has been found at Na-hkam^{324b} associated with many gastropods. Triassic bepls have also been recorded³²⁴⁶, and M. R. Sahni⁴⁶⁷ has since discovered a rich fauna of Lower Triassic ammonoids at Na-hkam, including species of *Ophiceras*, *Vishnuites*, *Hemiprionites*, *Aspenites*, *Kashmirites*, etc. The absence of all calcareous brachiopods is noticeable, only *Lingula* having been found. In the Jade Mines district the Permo-Carboniferous is intruded by a batholith of granite which is probably of Triassic age.

In Tenasserim⁴⁴, including Tavoy²⁴¹, and Mergui¹⁹⁰, there are limestones associated with shales and sandstones forming the *Moulmein Series*, with a thickness of about 5000 ft.; these beds have yielded marine fossils considered by Noetling⁴⁴ to indicate a Carboniferous age, but we may doubt whether they should not rather be referred to the Permian, as they show Salt Range and Sumatran affinities. Chhibber¹⁹⁹, however, keeps them in the Carboniferous. The limestone opposite Martaban Station²⁸⁶ is probably of the same age.

The Mergui Archipelago¹⁹⁰ consists of about 900 islands arranged apparently in four tectonic lines running approximately north and south, or N.N.W.-S.S.E., and parallel to the Tenasserim coast, with the intermediate channels representing tectonic valleys. The rocks (*Mergui Series*) consist of argillites, greywackes, quartzites and agglomerates, of doubtful age, and mostly thrown into narrow closely-set longitudinal folds with a strike corresponding to the tectonic lines. Whether this series of beds is of the same age as the Moulmein Series, or is partly Triassic, is a disputed point. No fossils have so far been found in the islands in these beds. As above remarked the *Mergui Series*^{190 199 241} may be partly Triassic, and Scrivenor suspects that it represents the Malayan Trias, but it probably includes beds of several stratigraphical horizons. Volcanic rocks occur in it in the Mergui Archipelago¹⁹⁰, and on Green Island³³⁸, off the Amherst coast, there is an igneous complex of late Mesozoic age, like some on the Malay Peninsula. On Elphinstone Island there are rhyolites and porphyries with tuffs and agglomerates, and they are invaded by an intrusion of granite. The Mergui Series also covers a large proportion of the mainland in the districts of Tavoy and Mergui.

Triassic beds are known to occur in the Arakan Yoma in Burma, where shales and limestones yield the characteristic lamellibranch genus *Daonella lommeli*, and the series appears to constitute much of that range. These Triassic beds belong to the Lower division of Theobald's *Axial Series*, which is developed in the Prome and Thayetmyo districts^{66 199 354 355}. (The Upper division of the *Axial Series* belongs to the Upper Cretaceous (see p. 439). In the Amherst district limestones containing an Upper Triassic fauna of corals, brachiopods¹⁹², and the ammonite *Trachyceras*, occur¹⁷⁵, and in the Karenni hills a limestone containing *Halobia* and *Monotis* is found. On the Burmo-Siamese frontier an Upper Triassic marine fauna of corals and mollusca has also been¹⁹² recently described. But in Yunnan fluviatile and fresh-water deposits with coal seams underlie the Rhaetic, and their presence suggests that terrestrial conditions may have also prevailed in Upper Burma.

The *Mhctic* or *Napeng Beds*^{18 41 287} of the Northern Shan States are marine deposits, and consist of shales, occasionally calcareous, which contain many peculiar lamellibranchs and some survivals of Palaeozoic types intermingled with typical Rhaetic species, such as the characteristic European *Avicula contorta*, *Grammatodon lycetii*, and *Gervillia precursor*, together with various species of *Myophoria*, *Modiola*, *Plicatula*, etc. These beds correspond with the Padang beds of Sumatra, which contain many of the same species.

In the neighbourhood of Kalaw, in the Southern Shan States^{175 211}, purple and red sandstones (the Red Beds) with coarse conglomerates and some coal-seams occur; in the latter plant-remains (*Cladophlebis denticulata* Brong., *Gingkoites digitata* Brong., *Pagiophyllum divaricatum* (Bunb.), *Braehyphyllum expansum* (Sternb.), *Ptilophyllum* sp., and *Podozamites distans* (Morr.) have been found, indicating a Rhaetic or Jurassic age. This series of red sandstones, etc., is widely spread in the Amherst district.

(b) Jurassic.

HIMALAYAS.—In the northern flank of the Himalayas there is (as above mentioned) no break between the Trias and Jurassic. The Lower, Middle,

and Upper Jurassic are represented by" limestones, 2000-3000 ft, thick, conformably resting on the Megalodon beds of Rhætic age. These limestones correspond to the Lias, Dogger, and Callovian; those corresponding to the Dogger contain *Stephanoceras*, etc., while the uppermost beds (Callovian) contain abundant belemnites (*B. sulcatus*). These beds pass up gradually into the important formation known as the *Spiti Shales*^{171 181 102}, which are about 500 ft. thick, and yield a characteristic and abundant fauna^{42 42a 42b} 291-293 of Upper Jurassic affinities, including many ammonites (*Oppelia*, *Perisphinctes*), belemnites, and lamellibranchs; this fauna shows that the beds must be correlated with the Portlandian and Argovian of Europe. Lithologically the shales are black in colour, splintery, and micaceous, with numerous calcareous concretions, and are remarkably uniform in character over the whole area of their distribution. They have a wide horizontal extent, being found in the Karakoram and northern Hazara, the Attock district^{222 291 292}, Nepal, and Sikkim, and they are also represented outside India in the Sula Islands of the Dutch East Indies and in New Guinea. In Tibet the Spiti Shales are said to cover large areas. In the eastern Himalayas the Jurassic beds are thrown into inverted close folds, and only a few obscure fossils have been obtained from them.

The fauna of the Spiti Shales¹⁰² 291-293 is allied to that of the Mediterranean province, but not to that of the Boreal (north Pacific) province. On the other hand, affinities with the fauna of the southern Andine region are conspicuous¹⁰². The distribution of sea and land rather than of climatic zones is believed to have been the more important and influential factor in determining its characters. The Spiti Shales pass up conformably into the overlying Cretaceous sandstone in the Himalayas (see below). There is an interesting and unique occurrence of supposed Jurassic beds with indeterminate fossils in the Lesser Himalayas east of the Ganges between the outer Tertiary zone and the main crystalline range. These beds, consisting of sandstones and shales with plant-remains, are known as the *Tal Series*, and extend over much of British Garhwal⁸⁰.

BALUCHISTAN.—In Baluchistan the main Mesozoic formations of the northern Himalayas are represented, but here the Lias also is present and consists of 3000-4000 ft, of black marine limestones and calcareous shales with a rich fauna; in it the chief European divisions have been recognised, and some of the species of fossils are identical.

Overlying these beds is a great thickness of massive limestones of approximately the same age as the Oolites of England; the uppermost part, which is known as the "*Polyphemus Limestone*" from the abundance of the ammonite *Epimayaites* (*Macrocephalites*) *polyphemus*, is considered to be of the same age as the Lower Kellaways of Europe. These limestones form the conspicuous peaks around Quetta.

SALT RANGE.—In the Salt Range, and especially in the western part of it across the Indus, there is a series of conglomeratic sandstones, shales, clays, and limestones in the lower part, with small patches of coal near the base of the series as near Kalabagh, a bed of haematite, and layers of a peculiar golden oolite which together represent a great part of the Jurassic and correspond more or less closely with the development of Jurassic beds in Cutch (see below) where they have been more closely studied. The Jurassic beds are diverse and inconstant in lithological character, and on a small scale in the cis-Indus section, but in the trans-Indus part of the range they have a thickness from 600 to 1500 ft. The lower portion of the series, which contains plant-remains as well as marine fossils, is referred to the Middle Jurassic, and

the upper part, which consists of highly fossiliferous limestones and black shales, yields a rich marine fauna of Upper Jurassic character.

In southern HAZABA the Jurassic rocks have a facies more like that of the Salt Range than of northern Hazara, where the Central Himalayan type (Spiti Shales) is represented.

CUTCH.—Owing to the subsidence of the Cutch-Rajputana area in Jurassic times this region was invaded by the sea, and therefore, unlike the rest of the Peninsula which remained land, possesses a series of marine deposits of considerable interest containing an abundant fauna^{259 372}.

In Cutch^{55-59 62} and in the Rajputana Desert near Jaisalmer⁸ and Bikaner these deposits form an important series of beds, ranging in age from about the Bathonian (Middle Jurassic) of Europe through the Upper Jurassic into the Neocomian without any decided unconformity. These deposits, which are of a littoral type and point to a temporary marine transgression and shallow water, form a number of islands surrounded by post-Tertiary beds; they are classified as follows:—

4. Umia Group (Portlandian to Neocomian). 3000 ft.
3. Katrol Group (Kimeridgian, Corallian, and Upper Oxfordian). 1000 ft.
2. Chari Group (Lower Oxfordian and Callovian). 1100 ft.
1. Patcham Group (Bathonian). 1000 ft.

Owing to the continuous depression which this area suffered during the accumulation of these beds, their thickness amounts to several thousand (6000) feet, though none of the beds is of deep-water formation. In Cutch the Jurassic beds crop out in three anticlinals running east and west.

The *Patcham Group* consists of yellow sandstones and limestones, which contain species of *Trigonia*, *Cucullæa*, *Corbula*, etc., with *Oppelia serriger* in the upper beds.

The *Chari Group* is chiefly composed of shales, with some calcareous bands and oolites (e.g. the Dhosa Oolite), and contains many ammonites and echinoids, some belonging to European species (e.g. *Macrocephalus macrocephalus*, *Peltoceras athleta*, *Holotypus sarthacensis*, *Collyrites dorsalis*). It seems to be about on the same horizon as the Polyphemus Limestone of Baluchistan.

The *Katrol Group* is of considerable thickness, and consists of red and yellow sandstones at the base containing many cephalopods, but the upper and preponderant rocks are shales. The commonest and most characteristic cephalopod is *Belemnites katrolensis*, and amongst the ammonites are species of *Oppelia*, *Harpoceras*, *Phylloceras*, and *Perisphinctes*. The ammonites in all these Jurassic beds of Cutch have been recently revised by Spath³⁷², and many new generic names have been introduced. Minor stratigraphical horizons have also been recognised in the succession. The Jurassic lamelli-branches of Cutch have also been revised by Cox²⁵⁹. There are some interstratified fresh-water beds in which are found plant-remains identical with those occurring in the Jabalpur Beds of the Gondwana System (see below), and some of these range up into the overlying Umia Group. Such are *Alethopteris whitbyensis* and species of *Sphenopteris*, *Otozamites*, and *Araucarites*.

The *Umia Group* is about 3000 ft. thick, and its surface-outcrop covers nearly half the Jurassic-Cretaceous area of Cutch. It consists principally of sandstone with some sandy shales and carbonaceous seams. Towards the base of the group is a thick band of calcareous conglomerate containing numerous marine fossils which are rare throughout the rest of the beds. The commonest and most important members of this marine fauna in the lower beds belong to the genus *Trigonia*, the species *T. smeei* and *T. ventricosa* being especially abundant. These¹⁰² species are also found in the Uitenhage Beds of South

Africa, which have been referred' to the Neocomian. But the numerous plant remains have close relations to those of the Jabalpur Group, and include *Alethopteris whiihyensis*, *Tceniopteris densinervis*, *Araucarites cutchensis*, *Ptilophyllum cutchensis*, *Otozamites contiguus*, etc. The plant beds are generally correlated for this reason with the Jabalpur Group of the Upper Gondwanas, at which horizon some marine beds are intercalated on the east coast (see below) and they resemble them also lithologically in their arenaceous and shaly character. But the occurrence of the cephalopod genera *Crioceras* and *Acanthoceras*³⁷² point to the reference of part of these beds to the Neocomian ; the evidence of the lamellibranchs in the lower part of the marine beds indicates the same age, and there seems to have been no break in this area in sedimentation between the Jurassic and Cretaceous, as is also the case in the Tendaguru area of Tanganyika (see p. 79). In northern Kathiawar there are Jurassic beds yielding cycads and other plants like those in the Umia beds, and they cover a considerable area.

In Rajputana³⁷¹ there are considerable outcrops of Jurassic rocks of the same general character. The highly fossiliferous Jaisalmer Limestone is correlated with the Chari Group, and is overlain by a series of sandstones and shales with some fossiliferous limestones.

BURMA.—In Burma¹⁸ in the Northern and Southern Shan States, and extending into Yunnan, is the *Namyau Series*^{205 208}, consisting of dark red sandstones, red marls, and shales with intercalated thin limestones. These yield numerous brachiopods (*Rhynchonella*, *Terebratula*³⁰⁵) and some lamellibranchs²⁰⁵, but no ammonites. The fauna proves that the age of the beds is Middle or Upper Jurassic, but probably more than one horizon is present. The affinities of the fauna are with the Jurassic of Kenya and Somaliland²⁰⁵, and probably of southern Arabia. The same fauna extends into Yunnan.

(c) Cretaceous.

CENTRAL HIMALAYAS.—In the Central Himalayas in the Tibetan zone the Spiti Shales are covered by a sandstone about 300 ft. thick known as the *Giupal Sandstone*⁴⁵, containing fragmentary fossils (*Gardium*, *Corbis*, *Aporrhais*) which indicate a Middle Neocomian to Upper Cretaceous age. The beds are of a Flysch-like character and occur also in northern Hazara³⁷¹⁷⁸, where the Giupal Sandstone has yielded a fauna closely related to that of the Gault of Europe¹⁷⁸. In north-west India there is a widespread stratigraphical gap between the representatives of the Gault and the beds of the Upper Cretaceous¹⁷⁸. The Gault¹⁷⁸ (Albian) horizon here, and to the east in the Hazara country, is characterised by the abundance of the European ammonite *Douvilleiceras mammillatum*. In the overlying limestone Cenomanian fossils of European species occur (*Acanthoceras mantelli*, *A. rhotomagense*, *Schlanbachia inflata*, etc.). But on the Giupal Sandstone in the Central Himalayas there rests the *Chikkim Series*, which consists of thick limestones and shales, in all about 250 ft. thick, containing a few fossils (foraminifera, *Hippurites* and *Belemnites*) indicating an Upper Cretaceous age. This series extends westward to Kashmir, Afghanistan, and Persia. In Spiti a great thickness of Flysch-like unfossiliferous sandstones and shales succeeds these beds, indicating a general shallowing of the Tethys and the first stage in the uplift of the mountain chain.

SALT RANGE.—In the Salt Range the Neocomian *Belemnite Beds*, consisting of shales and sandstones, have a rich fauna of ammonites, including many species of *Olcostephanus*³⁰⁹.

In the *Attock district*²²² Cretaceous beds succeed the Jurassic and contain an abundant fauna of ammonites, lamellibranchs, and other fossils^{291, 298}.

In the *Samana Range*²³¹ west of Kohat, fossiliferous Lower Cretaceous and Albian beds also occur.

CHITRAL.—In the Chitral area^{78 230} there are narrow faulted bands of Hippuritic and *Orbitolites* limestones, which are apparently succeeded by a conglomerate (the Reshun Conglomerate) of Upper Cretaceous or Lower Tertiary age. Douvills⁴⁶³ has described from Gilgit the rudistids *Horiopleura* and *Preradiolites*, as well as corals.

BALUCHISTAN.—In Baluchistan^{43 47} we find a series of shales and thin limestones resting on the Polyphemus Limestone and often containing volcanic material. These are the *Belemnite Beds*, as in the Salt Range, so-called from the abundance of *Belemnites* of the group *Duvalia* (*B. dilatatus*, *B. latus*) which occur with the ammonites *Hoplites* and *Olcostephanus* and other fossils⁸⁰⁹, some of the species being identical with those of the Speeton Clay of Yorkshire. The beds are referred to the JSTeocomian⁸⁰⁹. The limestone at the top of the Belemnite Beds is known as the *Park Limestone*, and consists of a series of siliceous limestones, 1500 ft. thick, extending nearly from Karachi to beyond Quetta. These Belemnite Beds have also been found in Waziristan⁴¹⁷ succeeding black shales of supposed Jurassic age. Above them, in Baluchistan, with a slight unconformity, come the so-called *Hemipneustes Beds*, a series of calcareous and arenaceous deposits 1500 ft. thick belonging to the Upper Cretaceous, and containing the echinoid *Hemipneustes pyrenaicus* and many other echinoids. Ammonites (*Sphenodiscus*, *Indoceras*, and *Pachydiscus*) occur in the succeeding shaly beds, together with *Badiolites* and *Orbitolites*. A large number of species which are found in the Maestrichtian of Europe have been recognised; the fresh-water gastropod *Physa prinsepi*, which is the commonest fossil of the 'Inter-trappean beds' between the Deccan lava-flows⁴⁹ (see below), occurs associated with the ammonites, a fact which is of some importance as it helps to fix the date of the volcanic activity in the Deccan.

In the State of Kelat⁴⁹ the ammonite shales are succeeded by a great thickness of sandstones, frequently with interbedded volcanic material, and known as the *Pab Sandstones*, the upper part of which corresponds with the 'Cardita Beaumonti beds' of Sind (see below). Above these Upper Cretaceous beds in Baluchistan there come true Eocene limestones containing nummulites (see below).

SIND.—In the Laki Range in Sind the Cretaceous System commences with a hard fossiliferous limestone containing echinoids (e.g. *Hemipneustes*) and mollusca, including *Hippurites*, and is referred to the Upper Cretaceous (Campanian or Maestrichtian), as in Baluchistan. This hippurite limestone is more widely developed in Persia, and extends through all Asia Minor into south-eastern Europe. Above it come sandstones, shales, and a limestone containing obscure reptile bones, and in one place there is a contemporaneous intercalated flow of basalt.

These beds are succeeded by olive-coloured shales known as the *Cardita Beaumonti beds* from the characteristic fossil³⁷⁴. They contain a rich fauna of a distinctive but transitional character, and the beds are correlated by some with the Montian³⁶⁸, but by others with the Danian or Maestrichtian of Europe^{49 874}. In Egypt a closely allied species of *Cardita* occurs in Maestrichtian and Danian beds, and in Luristan *C. (Venericardia) beaumonti* has been found associated with *Omphalocyclus* and *Hippurites*.

Interstratified with, as well as resting conformably on, the *Cardita Beaumonti* beds there are flows of basaltic lava resembling in all its characters the Deccan traps⁸⁰⁴, and succeeded regularly by the lowest Eocene (Ranikot beds). It

is frequently stated that there is no marked divisional line here between the Cretaceous and the Tertiary, but, according to Vredenburg²⁴⁹ and Pinfold⁴⁸², there is a stratigraphical break between the Cretaceous and Eocene as pronounced in India as in any other part of the world.

KASHMIR.—In Kashmir fossiliferous Cretaceous limestones are interbedded with volcanic ash, tuffs, agglomerates, and basaltic lava-flows. Thus Wadia⁴²⁴ has described volcanic, pyroclastic, hypabyssal, and plutonic igneous rocks from the Burzil basin, Kashmir, associated with Lower or Middle Cretaceous rocks containing the typical foraminifer *Orbitolina*.

BURMA²⁵⁶.—In the upper part (*Negrais*⁴⁶² *Series*) of the complex highly-folded so-called *Axial Group*¹⁹, of the Arakan Yoma, the characteristic Sind fossil *Cardita beaumonti*⁵⁶ has been found, as well as the Gault ammonite *Scifloenbachia inflata*. The whole series consists of chiefly unfossiliferous sandstones and shales of the Flysch type, and has trappean intercalations and ash-beds equivalent to the Deccan traps at the top of the series. Some of the intrusive serpentines^{170 199 256} which occur in this region are believed to be of Upper Cretaceous or Lower Eocene³⁶⁰ age, for the similar intrusive rocks in the Andamans where the 'Axial Group' is continued do not alter the Lower Eocene beds, but furnish pebbles for the Tertiary formations. The peridotite and serpentine boulders²⁴⁵ in the *Uru Conglomerate* of the Jade Mines area^{347 388} in the Myitkyina district which contain the veins of jadeite-albite have been derived from intrusions of this age (see *postea*). The occurrence of the Cretaceous foraminifer *Orbitolina* has been noted²⁴⁷ near the second defile on the Irrawaddy River, and Clegg²⁵⁶ has shown that Cretaceous and Tertiary rocks occur also in the First Defile, and he would further attribute the limestones in the Mogok area and in the Jade Mines^{847 888} area to the Cretaceous. On Ramri Island the Cretaceous ammonite *Mammites* (*Acanthoceras*) *daviesi*, which is allied to a Utatur species, has been found.

ASSAM.—Cretaceous rocks are found in the Khasi Hills⁴¹⁸ between Assam and Sylhet, and lie nearly horizontal on the denuded edges of the pre-Cambrian Shillong Series on the plateau, but along its southern edge they are bent down in a monoclinical flexure. The most persistent member of the series is a coarse hard sandstone 200 ft. thick. The *Cardita Beaumonti* beds with interstratified volcanic beds, as in Sind, succeed these sandstones, which have a flysch-like character. Some small and local seams of coal are found, and a few beds with marine fossils occur near Cherrapunji, which by the presence of many of the Ariyalur species of southern India suggest that the Pacific province extended into this region. The fauna²⁸² includes species of *Baculites*, *Inoceramus*, *Spondylus*, *Bostellaria*, etc., and indicate a Cenomanian age²³². Coal-fields exist in the Garo¹⁶³, Khasi⁴¹⁸, and Jaintia Hills, but are mostly of small importance. The oil-fields are concisely described by Sale and Evans²⁶⁴ and by Pascoe²⁰⁹. The principal rocks in all these Assam developments of the Cretaceous are sandstones and conglomerates. The folding and disturbance of the Cretaceous beds in this region probably took place in early Eocene times.

IGNEOUS ROCKS.—The igneous activity of the late Cretaceous and early Eocene times was marked by a widespread intrusion of serpentines and basic or ultrabasic rocks²⁵⁶ along lines which stretched southwards from the Naga and Manipur hills down to the Andaman and Nicobar Islands, and even farther south into Java and Sumatra. The line follows mostly the eastern flank of the Arakan Yoma, past Myitkyina, the Upper Chindwin, Henzada¹⁷⁰, Minbu, Bassein, Prome, and Thayetmyo districts. The intrusions, which

include peridotites, saxonites, lherzolites, and dunites, have caused alteration in the Negrais Series of rocks¹⁹⁹. In addition to these volcanic and intrusive igneous rocks in Burma, Sind, Kashmir, and Baluchistan, it is believed that some of the masses of granite and other plutonic rocks which constitute part of the core of the Himalayas were injected in late Cretaceous times, though most of them are more probably connected with the mid-Miocene upheaval. In Chitral the granite is intrusive in Jurassic beds. The igneous activity persisted in some of these regions into Tertiary times, as described below; the huge outpouring of basaltic lavas in the Deccan (see below), which began in Peninsular India as well as in Kashmir, Sind, Assam, and Burma in Cretaceous times, was likewise a phenomenon of the transitional period between the Mesozoic and Cainozoic eras¹⁶⁶. As in Assam so in Burma there were considerable earth-movements^{160 186 199 32B} at the close of the Cretaceous or early in the Eocene accompanying the break-up of Gondwanaland. Such produced the elevation of the Arakan Yoma and of the Shan plateau, with the formation of a great geosyncline between them.

(ii) PENINSULAR AREA.

(a) **Permian to Upper Jurassic.**

Gondwana System^{221 373 406}.—Above the youngest beds deposited during the Purana or Transition era in Peninsular India there is a great gap in the geological record; until we reach the Permo-Carboniferous period no deposits of any kind are known, and the whole region was apparently an area of extensive denudation.

There then began to be formed a great series of mainly fresh-water and terrestrial beds, chiefly sandstones and shales, with some coal-seams intercalated, which were laid down partly in depressions on the much eroded surface of the older rocks, and now form an enormous thickness of deposits of one general type and of great importance and interest.

They are partly of fluvialite and partly of lacustrine origin, but may in some cases have been of aeolian origin, and the famous basal bed of the series is claimed to be the result of glacial agencies. Only in one small area in the Gondwana System did marine conditions exist for a short period. This was in the Umaria coal-field¹⁹⁴ during the Barakar Stage. This thin series of marine beds contain species of *Praductus*, *Spirifer*, *Beticularia*, etc.^{194a}. In late Jurassic times the sea invaded several parts of the margin of the land-mass, and again in Cretaceous times, so that the east and west coasts of the Peninsula in places received marine deposits.

These beds constitute the **Gondwana System**^{221 345 373 406}, which is represented in East and South Africa by the Karroo System⁴⁰⁶, and by deposits of similar character in Australia and South America⁴⁰⁶. All these widely separated deposits⁸⁶⁸, forming a closely connected, though not uninterrupted, series of beds of Upper Palaeozoic and Mesozoic age, show a remarkable community of lithological characters and of conditions of sedimentation. The flora^{52 52a 107 149} 288-290 295 (and to a less extent the fauna⁸⁵²) of successive stages is also identical, many species ranging over the whole of this huge area in the southern hemisphere, and is believed to indicate a cold temperate climate. One great continental mass of land, though not necessarily quite continuous or uninterrupted, seems to have stretched round the southern hemisphere, and to have thus permitted the same fauna and flora to range freely over the whole region. This hypothetical continent has been termed Grondwanaland^{68 6r, 144 846}, and seems to have persisted in a more or less unbroken mass into late Mesozoic times, the identity or close relations of both **land plants**⁸⁸² and vertebrates⁸⁵² in these deposits throughout the present

southern continents and India bearing witness to land connections in spite of stratigraphical and palaeontological breaks. There is evidence also of widespread climatic changes from frigid to arid conditions^{288, 290}.

The northern shores of this continent seem to have approximately coincided with the central range of the Himalayas, and to the north spread the great Mediterranean Sea, the Tethys.

In Peninsular India, in Australia, in the Falkland Islands, in South America^{131 144}, and in South Africa⁸⁴⁸ (*q.v.*) the series of beds belonging to the Gondwana System has a peculiar boulder bed at its base, which is considered to be of glacial origin^{150 136 137 339}. In the case of South Africa and the Falkland Islands it has already been described in these pages. The succession of beds above it has a remarkable similarity in all these widely separated areas^{149 221 277}.

In India the Gondwana beds are preserved in the Peninsula mostly as small isolated patches or basins as the result of subsequent faulting or more rarely of folding into the older rocks, but they must originally have had a much wider extension, and have only been removed from the intervening tracts by subsequent denudation. Some geologists, however, believe that they were originally deposited in subsiding fault-troughs, while Lake¹⁵² has put forward the theory that they were laid down in arms of water between three principal land-masses of pre-Gondwana rocks in the Peninsula, and that the present borders of the basins coincide closely with the original shore-lines, the conditions of deposition having been much the same as those of the alluvial deposits of the Indo-Gangetic plain.

A few outlying patches occur in such distant spots as Assam, Sikkim, Bhutan, the Abor country, Kashmir, and Afghanistan. The occurrence of the Gondwana type of sediments with its characteristic plant-remains in association with marine beds has already been noted in Kashmir and the Salt Range.

The chief districts in India where the Gondwana beds are developed²²¹ are (1) in the Rajmahal Hills and the Damodar Valley in Bengal, where there is a series of faulted inliers with parallel boundaries, and an east and west linear arrangement along the valley; and (2) along the valleys of the Barakar, Mahanadi, and Godavari Rivers, where a similar disposition of the beds and similar structural relations prevail.

In the tributary Mahals of Orissa, Chhattisgarh, Chota Nagpur, the Upper Son Valley, the Satpura ranges south of the Nerbada Valley, and the Godavari Basin, there are other patches of larger or smaller extent.

It is rarely that the beds are covered by younger formations, except where the Deccan traps and their associated beds occur, as in the Nerbada Valley and Nagpur country. But in Cutch the marine Cretaceous rests on the Umia beds in which an Upper Gondwana flora is associated with marine Upper Jurassic or Neocomian fossils, as above described. In the Nerbada Valley the Cenomanian (Bagh) beds rest unconformably on the Gondwana, and the same relations to the Cretaceous are found at Utatur near Trichinopoly.

The lithological characters of the Gondwana System vary greatly, but an arenaceous facies is predominant, and the occurrence of valuable coal-seams^{249 269 270} makes the system of great economic importance.

Classification.—The Gondwana System is usually divided into a Lower and an Upper portion which in western Bengal are separated by a strong stratigraphical and palaeontological break, but elsewhere the break is not so marked, and a middle division is sometimes separated off'. A succession of distinct floras and floral provinces has been recognised in the Gondwana System in India, and it is largely by means of the plant-remains that the beds are classified and correlated^{288 290},

Lower Divisio'.—The Lower²⁴⁹ division contains the well-known *Gloaaopteris* flora¹⁰⁷¹⁴⁴, and is divided into three principal series known as follows (in descending order):—

3. Panchet Series.
2. Damuda Series.
1. Talchir Series.

These divisions are further subdivided into several stages, which are differently developed in those parts of the area in which the system is found ; gaps in the succession exist in some places, showing interruption in the deposition of the beds.

(1) The **Talchir Series** consists mainly of fine silty shales, mostly olive green in colour, and includes (generally at the base) the remarkable boulder-bed known as the Talchir Conglomerate. This boulder-bed contains pebbles and boulders from a quarter of an inch to 15 ft. in diameter, irregularly distributed in the matrix ; the pebbles are always rolled and usually well rounded, and may be faceted, scratched, or smoothed on some faces; the underlying rock is in some places scored and polished. The glacial origin of this boulder-bed or tillite is now generally admitted^{136 168}. The rest of the Talchir Series consists of sandstones and grits rarely containing a few plant-remains, including the typical genera *Glossopteris* and *Gangamopteris*. The thickness of the group is not above 800 ft. In the Salt Range, as above described, the boulder bed²²⁷, at the base of the Speckled Sandstone (Nilawan) Series, corresponds with the Talchir boulder-bed, and the occurrence of the *Glossopteris* flora in the Lower Produotus Limestone Series enables the correlation of the beds to be made with the marine equivalents^{146 279}. According to Du Toit³⁶³ and some other authorities all the basal glacial and associated interglacial deposits in India and other parts of Gondwanaland should be placed in the Carboniferous rather than in the Permian. But, whether we place them at the top of the Carboniferous or base of the Permian, it is acknowledged that they indicate a definite horizon of stratigraphical importance, and mark a major break in the succession of deposits over an immense area in the southern hemisphere.

In the Karharbari coal-field, Bengal, the upper beds of the Talchir Series are sometimes designated the *Karharbari Series*, and here contain valuable seams of coal. Fossil plants are numerous, including species of the two above-mentioned genera (*Gangamopteris cyclopteroides*, *Glossopteris indica*), *Noeggerathiopsis hislopi*, etc.

(2) The **Damuda Series** forms the chief coal-bearing set of beds in India, and is the most important member of the Gondwana System. In Bengal it is divided into three stages :—

3. Raniganj Stage.
2. Ironstone Shale Stage.
1. Barakar Stage.

But elsewhere not all the stages can be recognised.

The total thickness of the series sometimes reaches 10,000 ft., and consists of sandstones, shales, clay-ironstones, and coal-seams. They contain a large number of plants, including many species of *Glossopteris* (*Gl. communis*, *Gl. angvAtiflora*, *Gl. browniana*), together with *Gangamopteris cyclopteroides*, *Phyllothea indica*, *JSphenopteris polymorphs*, *Alethopteris lindleyana*, *Macrocteniopteris*, etc.

In the Damodar Valley the Barakar Stage is 2000-3300 ft. thick, and contains the most valuable coal-seams, some being 35-90 ft. thick. It is in the Barakar Stage that the only Permo-Carboniferous marine band^{194 194a} occurs, as above mentioned in the Umaria coal-field in the Rewah State. The middle

division in the Raniganj²⁷⁰ coal-field contains valuable lenses of clay-ironstone. The upper division includes in the same area additional important coal-seams. The Raniganj coal-field²⁷⁰ is one of the most important (see under 'Economic Minerals').

(3) The Panchet Series follows usually with a slight unconformity, and consists in Bengal of coarse felspathic and micaceous sandstones and bands of red clay, but it is destitute of coal-seams. The beds contain reptilian and amphibian remains and comparatively few plants. The vertebrates are of much importance, and include labyrinthodonts (*Gonioglyptus*, *Glyptognathua*) and anomodonts (*Dicynodon*), some of which occur also in South Africa. This series of beds is sometimes separated off as forming the basal portion of the Middle Gondwanas¹⁴⁵, with the Kamthi and Maleri Series (see below) of the Satpura region composing the upper members of the division. The difference in the fossil contents, the presence of an unconformity at the base of the Paytichet Series, and the absence of any coal-seams in the great mass of arenaceous deposits are held to justify this view. The *Parsora Stage*^{145 221 378} in South Rewah may be regarded as forming passage beds between the Panchet and Rajmahal Series.

Upper Division.—The Upper Gondwana division is separated from the Lower by a marked stratigraphical and paleontological break, and it contains quite a different flora and fauna, cycads and conifers being prevalent and the anomodonts being absent. The *Parsora* beds²²¹ are an exception in this respect.

In the central parts of the Peninsula the Mahadeva Series, reaching a thickness of 10,000 ft. in the Satpura²⁹⁶ region, is by some geologists put in a Middle division, but more usually is placed in the Upper; it consists of coarse red sandstones, grits, and conglomerates. The shales contain plant-remains, including survivors from the Damuda Series (*Glossopteris* and *Gangamopteris*) associated with *Pecopteris*, *Thinnfeldia*, etc., and some vertebrate remains similar to those in the Panchet beds. Wadia¹⁴⁵ puts this Mahadeva Series between the Panchet Series and the Maleri and *Parsora* Series. In the Rajmahal Hills the unfossiliferous red sandstones of the Mahadevas seem to be represented by the Dubrajpur sandstone which underlies unconformably the Rajmahal Series, and is considered by Wadia¹⁴⁵ to correspond to the Kamthi Series of the Central Provinces, a formation equated by some with the Raniganj, by others with the Panchet.

The Rajmahal Series in Bengal¹²⁰, which is the principal group of beds of this Upper division, consists typically of shales and sandstones yielding many plant-remains, and has interbedded flows of basaltic lava often amygdaloidal. It reaches a total thickness of 2000 ft.

The plants of the Rajmahal Series in Bengal^{396 459} include ferns (*Alethopteris indica*, *Thinnfeldia salicifolia*, *Sphenopteris arguta*, *Marattiopsis*, *Cladophlebis*, *Tceniopteris spatulata*), cycads (*Cycadites*, *Otozamites*, *Pterophyllum*, *Ptilophyllum*), conifers (*Palissya*), etc. The cycads are the predominant members of the flora. It is of special interest that the stem known as *Bucklandia indica* bore leaves of the *Ptilophyllum* type, but *Williainsonia* flowers²⁹⁵.

The underlying Lower Gondwanas are pierced and altered by intrusive dykes of two periods and of different petrological types, the older being mica-peridotites and the younger (which are probably connected with these contemporaneous Rajmahal lavas) being basalts. A similar association is noticeable in the homotaxial Upper Karroo beds of South Africa, where volcanic activity is likewise characteristic of this horizon.

The **Kota-Maleri Beds** of the Satpura region and Godavari Valley appear to *belong* partly to the same horizon as the Rajmahal Series, and are famous for their fish and reptilian remains.¹ The lower or Maleri Beds, which are referred by some authorities to the Middle Gondwanas, are chiefly red clays with thin bands of limestone and soft sandstones, and yield the fish *Ceratodus* and the reptiles *Hyperodapedon*, *Parasuchus*, etc., while in the Upper or Kota Beds, which are chiefly sandstones with three bands of limestone, there occur, in addition to the same vertebrates, *Belodon*, *Lepidotus*, and dinosaurs^{298 307} and the crustacean *Estheria*. The plants include conifers and numerous cycads resembling the Jabalpur forms.

The **Jabalpur Beds** occur typically near the town of that name, and are composed of clays, shales, earthy sandstones, with some beds of lignite, not more than 1000 ft. thick in all. This series rests unconformably on the underlying Maleri beds. Most of the characteristic Rajmahal plants are absent, and conifers (*Elatocladus*, *Retinosporites*, *Araucarites*, etc.) are the dominant group, and not cycads. The flora has more the stamp of that of the Umia beds of Cutch, already described, and includes the following: *Podozamites lanceolatus*, *Otozamites hislopi*, *Ptilophyllum acutifolium*, *Palissya indica*, *Araucarites cutchensis*, *Alethopteris lobifolia*, etc. These beds are usually referred to the Lower Jurassic and correlated with the Lower Oolite, but Matley¹⁵⁸ is of the opinion that they are probably Lower Cretaceous.

Various names are given to the other local developments of Upper Gondwana beds, and in some cases beds intermediate in age between the Rajmahal and Jabalpur Groups seem to be present.

BURMA.—The only trace of the equivalents of Lower Gondwana beds in the Martaban area is the occurrence of the lamellibranch genus *Palceano-donta*¹⁷²⁸⁶ in a series of shales and grits at one spot. But the limestone near Martaban Station²⁸⁶ may be of Triassic age. The *Loi-an Coalfield* of the Southern Shan States¹⁷⁵ near Kalaw contains the equivalent of an Upper Gondwana flora²⁸⁸, and some of the Red Sandstones of the Amherst¹⁷⁵ and Mergui¹⁹⁰ districts which, together with grits and conglomerates, are partly of fresh-water origin, contain plant-remains of Rhetic or Jurassic age, and should also probably be equated with the Upper Gondwanas.

Marine Intercalations.—Along the east coast of the Peninsula^{116118 119} there are isolated small patches of Upper Gondwana beds, with some marine deposits locally interbedded. Thus, in the Ellore district we find resting on sandstones containing Rajmahal plants a series of shales and thin sandstones known as the *Ragavapuram Shales*, containing many Rajmahal species of plants, and also some marine mollusca of Neocomian aspect. Above these shales come dark red and brown sandstones and conglomerates, known as the *Trigonia beds*, with fossil wood and occasionally some of the marine shells (*Trigonia ventricosa*, *Tr. smeei*) characteristic of the Umia beds of Cutch already described and referred to the Portlandian or Neocomian.

South of the Kistna near the town of Ongole there is another patch, with shales containing an abundant Upper Gondwana flora; and near Madras there are shales and sandy beds with a similar assemblage of plants and some mollusca.

The ammonites from these coastal deposits (*Holcodiscus*, etc.) tend to prove that they are of Lower Cretaceous (Barremian) instead of Jurassic age.

¹ The Kota beds are now believed to be considerably younger than the Maleri and are separated therefrom by an appreciable gap.—E. H. P.

Correlation.—The whole Upper Gondwana division corresponds in a general way to the Triassic and Jurassic periods of Europe, but is closely linked with, or partly belongs to, the Lower Cretaceous, as is seen in the Jabalpur and Umia beds.

The question of the correlation of its various members has been a vexed one¹⁴⁹, but the local, though rare, intercalation of marine beds with characteristic fossils enables us occasionally to fix their position, as in the case of the Umia beds of Cutch. Just as in the case of the Lower Gondwanas, we find that the Upper Gondwana flora, together with the physical conditions which accompanied it, had a very wide distribution, and was especially characteristic of the southern hemisphere, being spread throughout India, Australia, and South Africa. The continent of Gondwanaland cannot be considered to have been completely broken up or submerged till after this widely-spread flora had been developed and had more or less disappeared.

(i) Cretaceous (wholly marine) of the Peninsula.

In the south-east Peninsular area the Cretaceous System has a purely marine development and occurs in only very limited patches, and there is evidence that there were merely marginal incursions of the sea over the now dismembered Gondwanaland.

SOUTHERN INDIA.—The Cretaceous beds of southern India are of a type completely different from that already described in Sind and the more northern region, and the fauna belongs to an entirely distinct zoo-geographical province^{60 61 101}. They are developed in the great plain extending along the Cojmandel coast from the mouth of the Godavari to Cape Comorin. In the west they lie directly upon the Archaean or upon patches of the Upper Gondwanas, and have a low dip to the east, where they are overlain by Pleistocene and Recent deposits. They are exposed in three chief areas south of Madras, the southern and largest of which is in the Trichinopoly district, and the principal northern one is at Pondicherry. They have been also found in the southern portion of the Cauvery delta.

In the *Trichinopoly area*, where they have their fullest development, they are divided into four stages, known (in descending order) as follows:—

4. Niniyur Stage,
3. Ariyalur Stage,
2. Trichinopoly Stage,
1. Utatur Stage,

and each stage is divisible into several zones.

(1) The Utatur Stage is chiefly argillaceous, consisting of shales and clays, about 1000 ft. in thickness, with usually a coral-reef limestone at the base. The fossils include many ammonites and other mollusca, and fragments of cycadaceous wood. Many European or widely distributed species of cephalopoda occur in the fauna.

The lowest of the three zones into which the stage is divided is marked by the almost cosmopolitan species *Mortoniceras inflatim*, but the majority of the fossils are closely allied to or identical with those found in the Pacific province.

The succeeding *Mantelliceras mantelli* zone, also an Atlantic species, yields many species of the genus *Acanthoceras*, and the uppermost zone marks the incoming of the Turonian conditions by the presence of *Inoceramus labiatus*. This upper zone is known as the *Mammites conciliatus* zone, and the whole stage is now correlated with the Cenomanian. Its total thickness is about 1000 ft.

(2) The succeeding **Trichinopoly Stage** follows after a slight stratigraphical

break and is marked by a considerable change in the fauna. It consists typically of about 1000 ft. of clays and sands very irregularly bedded, with intercalated bands of shelly limestone, grits, and conglomerates, and it contains an abundance of fossil wood in addition to marine organisms. The plant-remains are chiefly cycads, and the tree-trunks reach a large size. Two ammonite zones are recognised, characterised by species of *Pachydiscus* and *Placenticerus*, and correlated respectively with the Turonian and Lower Senonian. Gastropods and lamellibranchs are numerous, and include *Pttgnellus uncatus*, *Fasciolaria rigida*, *Chemnitzia undosa*, *Euchrysalis gigantea*, etc.

(3) The Ariyalur Stage is considered equivalent to the Upper Senonian and rests conformably on the Trichinopoly. It consists chiefly of white unfossiliferous sands with a few calcareous bands containing fossils. The fauna is very rich; the lamellibranch *Trigonoarm galdrina* is especially abundant, and species of the cephalopods *Pachydiacus* and *Baculites* are characteristic; the *Cyprceidae* and *Volutidae* are also well represented. The dinosaur *Megalosaurus* and other genera of reptiles are also recorded from these beds^{196 301},

(4) The Niniyur Stage, which is not separated by any stratigraphical break from the Ariyalur, is characterised by the cephalopod *Nautilus danicus*, the typical Danian species of Europe, and is therefore correlated with the Danian. Many foraminifera and algae also occur, and all the typical Mesozoic genera abundant in the Ariyalur Stage have disappeared, including the ammonites. The beds comprise argillaceous and arenaceous deposits, with flints and cherts, together with numerous intercalated algal^{880 880} and foraminiferal limestones. This Niniyur Stage is considered equivalent to the Cardita Beaumonti beds of Sind (see p. 438).

In the Pondicherry area the Cretaceous beds are regarded as belonging only to the Ariyalur and Niniyur Stages, and they yield a very rich fauna. Three horizons are recognised possessing the typical fossils of the other area, but in the uppermost horizon, which is alone referred to the Niniyur, large species of *Nerinea* are particularly abundant.

These Cretaceous beds of southern India belong to the great Indo-Pacific zoo-geographical province of that period, and representatives of them are found in Assam, Borneo, Japan, Vancouver Island, California, Chili, New Zealand, Madagascar, and South Africa, many of the fossils in these widely separated regions being identical. One more or less continuous sea must have spread over the whole area at this period. In the western part of the zoological province and in the lower beds there is a mixture of European forms, but otherwise the fauna has a distinct individuality, and points to the existence of barriers between the oceans demarcating the life-provinces and preventing the free intercourse and migration of their inhabitants.

NARBADA VALLEY.—In the western portion of the Narbada Valley there are certain interesting Cretaceous beds^{108-110 234 284}, known as *the Bagh Beds*, which contain a fauna⁸⁷⁷ possessing much closer affinities to the European Cretaceous than to that of southern India¹⁷⁸. There must have been some kind of barrier separating the two seas and areas of deposition, and it is believed to have been a portion of the old Gondwanaland. The fossiliferous beds, which are only 50-80 ft. thick, consist of argillaceous, coralline, and nodular limestones, and lie on unfossiliferous sandstones and conglomerates, which in their turn rest unconformably on the Archasan rocks, etc. The rich marine fauna consists largely of echinoids^{46 377}, some of which are European species, but others resemble those of Arabia and Palestine; many mollusca, including ammonites, are also present. The beds have been usually referred to the

Onomanian, and regarded therefore as of the same age as the Utatur beds of the southern province, but Fourtau correlated them with the Upper Gault. Recent revision of the fauna shows that the Bagh Beds cover **a much longer** period, **and** that their age ranges from Cenomanian to Upper Senonian^{284 377} 377a 8 77b 877c 468. The distinction of the European and Pacific zoological provinces in Cretaceous times is strikingly brought out in the composition **of the fauna** of these Narbada deposits.

(ii) **Cretaceous (fresh-water and volcanic) of the Peninsula.**

(1) **The Lameta Series**^{108 109 158 234}.—The great volcanic series known as the Deccan traps or Trappean Series, which covers even now an immense area (though only a fragment of it has been left owing to extensive denudation), is underlain in places, especially round its borders, by a series of fresh-water sedimentary beds, known as the *Infra-trappean* or *Lameta Series*, which are of considerable interest, and though of small thickness extend over a considerable area, generally as discontinuous bands. Limestones of a siliceous nature and containing chert-nodules are the most characteristic rocks, and are now considered to be largely metasomatic in origin, having been formed by the calcification and silicification of the underlying Archæan gneisses and schists. These beds, which are only 20-100 ft. thick, are quite unconformable to the underlying formations and rest in places on Jabalpur beds, though generally on the gneiss, but the lowest lava-flows of the Deccan Series as a rule lie conformably upon them, though local unconformities seem to occur. The principal development of this group of beds is found in the Central Provinces around Nagpur and Jabalpur. As a rule it is unfossiliferous, but some of the sandstones and clays have yielded fresh-water shells of *Paludina*, *Mekcnia*, *Corbicula*, etc., and twelve genera of dinosaurs have been discovered^{196 298}, including *Titanosaurus*, *Antarctosaurus*, and *Indosuchus*. Fish-remains, including *Lepidosteus* and *Pycnodus*, also have been recorded. The dinosaurs are said²⁹⁸ to be closely allied to those found in Madagascar, Patagonia, and Brazil. The evidence of the vertebrate remains indicates that the beds belong to the late Cretaceous rather than to the Eocene, and are probably of Danian age.

(2) **The Deccan Traps and Inter-trappean Series.**—The enormous development of basaltic lava-flows in central India^{117 169 204 234 299 468} is one of the most striking features of its geology. These lava-flows, which preserve a remarkable horizontality, form flat-topped hills, plateaus, terraces, and scarps, some 4000 ft. high, and their remains, though much reduced by long erosion, **still** cover an area of 200,000 sq. miles. Outliers of them occur as far apart as Sind in the west and Rajahmundry in the east. The separate **lava-flows** are generally of a thickness varying from 6 to 90 ft., and are **usually** only separable by petrological characters. The prevailing type of rock is olivine-basalt or augite-andesite, but there is a considerable variation in composition, and in some parts of Gujarat rhyolites and trachytes are associated. **The** petrological characters of the Deccan traps and their chemical composition have been investigated by Fermor³⁰³ and Washington²⁹⁹. The flows are **often** amygdaloidal, and contain zeolites and agates, and columnar jointing is frequently present. Beds of interstratified volcanic ash **and** tuff are **fairly common, and** some sedimentary beds, which are known as the *Inter-trappean Series*, are interstratified in places and contain fossils.

An Upper, Middle, and Lower Series of traps has been recognised; **the Middle one' is distinguished by the absence of intercalated fossiliferous sedimentary beds.**

The total thickness of the Deccan traps is not constant, **the variation**

being due partly to original differences of thickness and partly to erosion. Near Bombay it is probably over 6000 ft., or, according to some calculations, nearly 10,000 ft.; in Cutch it is about 2500 ft., while in Sind the whole series is much reduced, being represented by two thin flows, each less than 100 ft. thick. In the Girnar Hills of Kathiawar there is a gabbroid complex comprising various petrological types⁵⁰⁰ ranging from gabbro, lamprophyre, limburgite, diorite, and syenite, to granophyre, and showing magmatic differentiation³⁴¹. This laccolite is of later date than the principal Deccan lava-flows, for it arches them up.

In Baluchistan the volcanic material associated with the Pab Sandstones (see p. 438) indicates the extension of the eruptions to this area.

The *Inter-trappean beds*¹¹⁷, which are intercalated with the lavas of the Upper and Middle traps, fall accordingly into a Lower and an Upper group. The Lower beds occur near the base of the volcanic formation in the Central Provinces, northern Hyderabad, Berar, and the States north of the Nerbada Valley. They comprise thin bands of chert, limestone, shale, and clay, with a few conglomerates or sands, and are of fresh-water or terrestrial origin with abundant fossils. The most conspicuous bed is a compact black cherty rock. The whole series rarely exceeds a few feet in thickness. The mollusca are very well preserved and frequently silicified, and include *Corbicula*, *Viviparus*, *Limnæa*, and *Physa prinsepi*; the last-mentioned, which is the commonest shell, has been also found (as previously mentioned⁴⁹) associated with Senonian or Maestrichtian ammonites in Baluchistan (see p. 438). Entomostraca (*Gypris*), insects, fish⁴⁶¹, and reptiles are also found, and the plant-remains include *Chara* and many algae³⁸⁰. In the Nagpur-chhindwara area the fossil flora from the base of the Trappean Series is marked by an abundance of palms, including *Nipadites*, which is a characteristic Eocene genus, and Sahni^{288 295} considers that the plants of the Inter-trappean beds show closest affinities with those of the London Clay (Lower Eocene).

At Rajamundry, on the east coast, a distinctly estuarine fauna occurs in a limestone belonging to a series of these beds, and includes species of *Cerithium*, *Tympanotomy*, *Potamides*, *Cytherea*, *Corbula*, etc., and it is believed that they correspond with the Pab Sandstones of Baluchistan. The Inter-trappean beds at Rajamundry, which are classed by some geologists as Eocene, contain also many fossil algae³⁸⁰.

The date of the commencement of the volcanic eruptions in western India is indicated by the occurrence of *Physa prinsepi* in the Senonian of Baluchistan and by the intercalated lava-flow in the Cretaceous *Cardita* Beaumonti beds of Sind.* It cannot have been before Cenomanian times, for the lavas rest in places on the Lameta Group and Bagh Beds. The volcanicity had died out before the Eocene Nummulitics were deposited, for the Ranikot Group of Sind which rests on a lava-flow contains no volcanic material in it or above it, and the traps are unconformably succeeded by Nummulitic beds at Surat and Broach. The subsidence of the north-western fringe of the volcanic area below the Eocene sea allowed of the deposition of these marine beds, but to the south-east the area has remained above sea-level to the present day, and has suffered continual sub-aerial denudation, producing the typical scenery of the Deccan.

The Upper Inter-trappean beds are found only in the vicinity of Bombay near the top of the volcanic series in the Upper Traps. One bed on Malabar Hill is 100 ft. thick in places, and consists of soft shales composed of volcanic detritus and bituminous in character. Plants, entomostraca, mollusca, and reptilian and amphibian remains are found in them, but none of the characteristic fossils of the Lower Inter-trappean Group.

* This is believed by Crookshank to be an intrusion.—E. H. P.

It is believed that all these lavas were poured out by 'fissure eruptions,' no true cones or definite volcanic vents having been detected. But special centres of eruption seem to have existed, and are marked by the abundance and size of the dykes; in Cutch, Kathiawar, and the Lower Narbada Valley there is clear evidence of volcanic foci. Near Shikarpur certain circular depressions may indicate outlets for lava or gases, and the Lonar Lake crater in Berar⁶³ has been thought to owe its formation to explosive action after the pouring out of the lavas.

Palæogeography of Aryan Era.—The existence of a great southern continent in Palæozoic and Mesozoic times, and its persistence to an even later date in a more or less connected form, has long received support from geological evidence, and zoologists have also postulated the former continuity of India and Africa as a land-mass under the name Lemuria. These existing land-areas are regarded as the fragments of a former continuous land-mass^{348 345} to which Suess gave the name Gondwanaland, and the geological and palæontological evidence on which the theory depends is very strong. The whole history and structure of South Africa and the Indian Peninsula have many peculiar features in common. For example, the Archaean and Pre-Cambrian basement in each of these areas is separated by a widespread unconformity and great stratigraphical gap from the next succeeding formation, which is of Permo-Carboniferous or late Carboniferous age, and this has everywhere at its base a conglomerate of a peculiar character, and probably of glacial origin. A similar conglomerate is found at this horizon throughout the southern hemisphere, and it is succeeded in India, South Africa, the Falkland Isles, South America, and Australia by a huge succession of fresh-water and terrestrial deposits containing a flora of the same type and many common genera and species of land-reptiles and amphibia. Deposits possessing the same characters continued to be accumulated without interruption over this vast area till Triassic or early Jurassic times, the close resemblance between the beds in India and South Africa being especially noticeable. The occurrence of volcanic activity of the same general character in both regions is another important feature of the period. The date of the dissolution of this great continent is not precisely determined, but it was a process of many stages, and was not simultaneous or uniform over its whole extent. The tendency⁴¹¹ for faults to be formed across the northern part of Gondwanaland with a trend varying from W.S.W.-E.N.E. to W.N.W.-E.S.E. began far back in Palæozoic times, and the later movements followed the same general lines. In late Cretaceous times the difference between the Indo-Pacific and European marine faunas suggests that a more or less effective land-barrier still existed across the Indian Ocean. But in India the culmination of the development of the fissures with a general east and west trend took place at the end of the Cretaceous period, and the molten material of the Deccan eruptions welled up through them and spread out over the surface as horizontal sheets of lava or formed dykes, the parallelism of which to the faults has often been noticed⁴¹¹. The truncated edge of the tableland in South Africa (where the marginal faults involve the Tertiary beds) and the similarly abruptly broken edge of the volcanic plateau of the Indian Peninsula prove that some of the downward movements took place much later and in post-Cretaceous times. Madagascar may be regarded as a horst left standing up in the midst of the sunken area, and the Seychelles are another fragment of the founded continental mass. The outlines of South Africa and of the Indian Peninsula have been determined by long faults with downthrows respectively to the east and west. The structure of the sub-oceanic floor⁴²⁸ supports this view of their origin. In Burma^{160 186 329} the main folding of the Shan plateau and the initiation of the Shan Boundary fault

along its west side as well as the earlier stages of the uprise of the Arakan Yoma on the other side of the Irrawaddy Valley took place in pre-Tertiary, or even late Cretaceous, times, according to Stamp¹⁶⁰, thus leaving a great gulf (or perhaps rift valley) between them which was gradually filled up by Tertiary deposits, the sea retreating on the whole towards the south, but with periodic marine advances northwards. Clegg²⁵⁶ has given a somewhat different interpretation of the succession of events.

Zoologists have demanded the existence of a land-mass (Lemuria) in the western Indian Ocean as late as the development of the land-faunas of the present Oriental and African life-provinces in order to explain their distribution. Geologically, however, we have no clear evidence of such a late survival of the ancient continent, and the breaking up of Gondwanaland cannot be put later than the end of the Cretaceous or early Tertiary, though some fragments of it may not have been submerged until a later date. Wegener's theory of drifting continents⁸⁴⁸ offers an explanation of the way in which Gondwanaland was broken up, and is upheld by Du Toit³⁴³.

TERTIARY³⁷⁸

During the Tertiary era the crust-movements which have determined the main surface-features of India were in operation, and from the date of the breaking up of the old Gondwana continent onwards there commenced the slow but intermittent rise of the ocean basin of the Tethys and the upheaval of the Himalayas. (The details of the three great phases of the movement are here deferred till the various Tertiary formations have been described.)

In many parts of India there is no physical break between the Cretaceous and Eocene, though in the north-west³⁶⁸ there occurred certain geographical changes. There are, however, important differences in the faunas of the two periods. The correlation of the marine and terrestrial Tertiary deposits in India and Burma is difficult, but Pilgrim³⁷⁸ has put forward a satisfactory scheme. The succession of Tertiary beds is nearly complete in some places, as on the Potwar plateau^{140 251 326 332}, where the whole series from the Eocene to the Pleistocene, with the exception of the Oligocene, can be traced.

(i) Eocene, Oligocene, and Miocene.

(A) *Western Region* : SIND AND BALUCHISTAN^{67 68 74}.—At the close of the Cretaceous period, while the great lava-flows were being poured out over the Peninsula, marine deposits were being laid down over the western and north-western margins of India, and parts of them are preserved in Sind^{122 172} and Baluchistan. We have already described the Cardita Beaumonti and associated transitional beds, but resting on them in Sind we have the oldest true Eocene beds in India, while in parts of this region there is a remarkably complete development of marine formations ranging up from the Eocene to the Miocene or Pliocene.

The following divisions have been established^{65 68 87} in Sind :—

5. Manchhar Group	
4. Mekran* „ . .	{ Hinglaj Series.
	{ 'Gaj „
	{ Nari ,
3. Kirthar „	
2. Laki	
1. Ranikot „	

' The term Makran (Mekran) has been used for successions with widely differing limits (see *Mem. Geol. Surv. Ind.*, li., p. 114 (1938).—E. H. P.

(1) The lower part of the **Ranikot Group** in Sind^{172 368} consists of sandstones, with gypsum, and carbonaceous shales, and contains only a few fossils. The beds seem to have had a fresh-water and fluvial origin, and rest with apparent conformity on the Cardita Beaumonti Series.

The upper part consists of very fossiliferous marine limestones interstratified with sandstones, clays, and shales, and contains a distinct Tertiary marine fauna²³¹, including abundant echinoids and corals, with nummulites belonging principally to the species *N. nuttalli*. These upper beds are correlated with the London Clay (Ypresian). The total thickness of the Ranikot Group in Sind is estimated at 2000 ft. The Ranikot fauna is distinct from the European Eocene, and such peculiarly eastern foraminiferal genera as *Dictyoconoides* and *Sakesaria* first appear³⁶⁸, while Indo-Pacific rather than European affinities are shown by other members of the fauna. The Ranikot Sea apparently had two arms, one extending northwards and eastwards from the Punjab and Sind into Tibet, and the other westward and northward to the Persian Gulf, but it had no connection with the Tethys, according to Davies³⁶⁸. But at the close of Ranikot times the connection was re-established.

(2) The **Laki Group** is in places arenaceous, but in others is calcareous, and in the Punjab and Baluchistan it becomes a coal-bearing series of economic importance. The limestones abound in foraminifera of the genus *Alveolina*, and the characteristic nummulites are *N. atacicus* and *Assilina granulosa*. In Sind it reaches a thickness of 500-800 ft., and Nuttall³⁰⁴ recognises three subdivisions in it, consisting of an upper and lower limestone, having slightly different faunas, and separated by shales. Cox³⁴⁰ has described many of the mollusca of this formation. In Baluchistan^{312 422} between the Bolan Pass and the Suleiman foot-hills the lowest subdivision of the Laki is represented by the *Dunghan Limestone* of varying thickness which rests unconformably on Cretaceous beds, and is followed by the *Ghazij Shales*. The Laki here differs in its development and lithological characters from the Laki of Sind, Kohat, and the north-west Punjab.

(3) The **Kirthar Group**³¹² consists largely of nummulitic limestones, but in eastern Baluchistan it becomes arenaceous. The limestones enter largely into the formation of the higher mountain-ranges along the Sind-Baluchistan frontier, and in the Kirthar Range are 3000 ft. thick. The Kirthar is one of the most important formations in the northern part of the Extra-peninsular region and is represented eastwards in Burma and westwards in Europe, where it constitutes the *Nummulitic Formation*, extending through Iran, Turkey, and Greece to the Pyrenees, and also stretching across much of North Africa. The Upper Kirthar beds are best developed in Baluchistan³¹². Echinoids and mollusca³⁴⁰ are abundant, and the gastropod *Velates schmideliana* * is a characteristic shell. Nummulites are specially abundant, and include *N. Icevigatus*, *N. perforatus*, *N. gizehensis*, etc.; the uppermost beds contain *N. complanatus*.

The Laki and Kirthar Groups are referable to the Middle Eocene. The molluscan fauna has been studied by Cox³⁴⁰. No Upper Eocene is present, except perhaps in the Mula Pass of Baluchistan, and there is a widespread unconformity between the Kirthar and the Oligocene, but this is not apparent in Sind, where the Nari Stage follows the Kirthar with apparent conformity.

(4) The beds corresponding to the Oligocene and Lower Miocene are here divided into three series, the Nari, Gaj, and Hinglaj, and the whole succession has been called the **Mekran Group**, with a total thickness of 7000-8000 ft. The

* *Velates peryersus* (Gmel.).—E. H. P.

Nari Series consists of massive limestones with large nummulites (*N. intermedins*, *N. vascus*); in the upper beds the nummulites attain their highest development. But in Sind itself the Upper Nari is represented by unfossiliferous fresh-water beds 4000-6000 ft. thick, which pass up gradually into the marine Gaj Series. Where the Nari is of marine origin echinoids and mollusca abound and amongst the former include species of the genera *Breynia*, *Clypeaster*, and *Eupatagus*. The mollusca of the post-Eocene beds of north-west India have been mostly described by Vredenburg³¹⁵.

The succeeding Gaj Series consists of shales and coral-limestones. True nummulites have here disappeared, and many new genera make their first appearance. A typical fossil is *Ostrea latimarginata*.

The Gaj beds pass up gradually into estuarine sandstones, clays, and conglomerates of Lower and Middle Miocene age, which are specially developed along the coast of the Persian Gulf, and are known as the Hinglaj Series. They are 4000 ft. thick, and the uppermost beds contain numerous large species of *Pecten* (e.g. *P. vasseli*, which is also found in the Miocene of Suez).

In north-west Baluchistan^{68 76}, and on the Mekran coast, there is a Flysch facies of the Nari Stage, known as the *Khojak Shales*. These beds, which consist of sandstones and shales, are almost unfossiliferous, but have yielded the characteristic nummulites *N. intermedins* and *N. vascus*. Recently the foraminifera *Lepidocyclina* (*Eulepidina*) *dilatata* (Mich.), *Camerina fichteli* Mich., and other species have been found in these shales at Pishin, proving an Upper Oligocene (Nari) age. In most parts of Baluchistan the typical calcareous development is found as in Sind, but in the Bugti Hills in eastern Baluchistan^{68 69 74 411 448} there is a fluvialite bone bed of Upper Gaj age, containing mammalian remains⁴⁶⁵ (*Anthracoherium*, *Baluchitherium*, *Brachyodus*, etc.), which rests on a marine band of Nari age with *NummtUites intermedius*, and is unconformably overlain by the Lower Siwalik Series. These Bugti beds consist of fresh-water sandstones, and the fauna has Lower Miocene or Upper Oligocene affinities.

It is of much interest to find that in Baluchistan^{77 78} volcanic activity persisted from Cretaceous into Tertiary times, and some of the basic eruptives and beds of volcanic ash, as well as intrusions of basic plutonic rocks, belong to the Eocene. The equivalents of the Ranikot and Kirthar beds, with their characteristic fossils, are found in places overlying submarine tuffs. The volcanic rocks include basaltic and andesitic lavas and tuffs, and these are interbedded with deposits of the Flysch type. It is possible that the large granitic and dioritic intrusions of this region may also be partly of Eocene age, as well as partly late Cretaceous, but some at any rate seem to be late Miocene or post-Miocene (see below).

In the Tochi Valley volcanic rocks are similarly interbedded with the Eocene, and are associated with intrusive serpentine, etc.; in the Takki Zam Valley, Waziristan⁴²⁰, the Nummulitic Series also is found.

In Cutch, Kathiawar, Surat, and Broach portions of the Eocene Nummulitic Series occur having a similar character to that in Sind, the Laki, Kirthar and Gaj Groups being especially well developed in Cutch. The lower beds in Cutch consist of a series of red and mottled clays, shales, and gypsum, resting on the Deccan traps, and passing up into limestones with the Kirthar nummulitic fauna. In Gujarat the Kirthar Series is represented by beds of sandstone, clay, gravel, and limestone.

In Rajputana outliers of the Laki and Kirthar beds occur in Bikaner and Jaisalmer. The Palana coalfield in the Bikaner State is in Laki beds, which are here well developed⁶.

Local Developments of Tertiary Rocks in the Western Region.

(1) KOHAT.—In the Kohat^{413 414} district west of the Indus there is a remarkable development of peculiar Tertiary beds⁸⁸⁰. At the base are beds of rock-salt⁴²⁸ and gypsum of much economic importance. The salt is more or less crystalline and pure, and occurs in immense masses, the beds being 300-700 ft. thick. Associated with it are shales and sands as well as layers of gypsum. The base of the series is not seen, but the rock-salt is succeeded by gypsum and clays, and these by Kirthar nummulitic limestones and red clays with apparent conformity. At Bahadur Khel⁴¹⁴, where there is a fine section, a lower zone of massive gypsum is succeeded by subordinate clay partings and cores of limestones with thin-bedded gypsum having crumpled bedding. Above come red clays and thin limestones followed by the *Kohat Shales*⁴¹³ containing *Nummulites atacicus* and other foraminifera referred to the Chharat (Upper Laki) Series. The gypsiferous beds and massive gypsum below are also correlated with the Laki stage of the Eocene, and are separated by a thrust-plane or unconformity from the massive rock-salt below, which is correlated with the Ranikot (Lower Eocene) by Wadia and Davies⁴¹⁴. The rock-salt^{864 414} differs from that in the Saline Series³³² of the Salt Range⁹⁸, (see below) by being almost pure sodium chloride without any admixture of potassium or magnesium salts, and also by being slightly bituminous. The Kohat Shales in this section are succeeded by typical Kirthar (Nummulitic) beds. In the *Samaria Range*, north-west of Kohat, the lowest Eocene beds known in India are termed the *Hangu Shales*²³¹, and have yielded an abundant molluscan fauna of Ranikot age.

In *Hazara* the Ranikot and Laki Series have a strong development of limestones which are succeeded in the Potwar area to the south by fresh-water shales containing mollusca (*Planorbis*, etc.). The Kirthar Series⁸¹² is represented by the Kohat Shales and Nummulitic Shales constituting the *Chharat Series*. The Ranikot beds have poor coal-seams in these regions.

(2) SALT RANGE^{302 331 383}.—Probably the Salt Marl^{128 332 426a} below the Cambrian beds of the Salt Range belongs to the same series as the Kohat beds, but the indubitable Eocene³⁰⁸ of the Salt Range is represented along its whole length. The Ranikot Series³⁰⁸ in the Salt Range is represented by a ferruginous pisolite at its base, followed by shales and limestones with local names. The shales are predominant in the eastern part of the range, and contain thin coal-seams. The Laki is chiefly represented by massive nummulitic limestones, and in the north-western part of the Range pass up into massive gypsum, which is supposed to be due to the alteration of limestone, and is associated with red marl and salt forming the so-called ' *Saline Series* '^{267 364}. The salt is largely worked at Khewra, Warcha, and Kalabagh. As above stated in connection with the Cambrian rocks of the Salt Range, the age of the Saline Series is still a matter of dispute^{267 302 331 332 381 381a-b 383426}, some geologists maintaining that the series has a conformable junction with the Purple Sandstone of the Cambrian and belongs to the same period, while others regard its position to be due to overthrust^{176 182 383} and its age to be Tertiary. The latter view is supported strongly by the recent discovery of Tertiary plant-remains in the marly layers (*kallar*) between the rock-salt masses and also in the dolomites and oil-shales, as recorded by Sahni^{881 381a-b}. The presence of overfolds and thrusts causing inversion of the order of the Cambrian and Tertiary strata has been recognised by many geologists^{176 182 383} in the Salt Range, and, coupled with Sahni's discoveries, it seems to offer a satisfactory solution of the problem of the age of the Saline Series⁴⁷⁸. The presence²³⁹, however, of Eocene foraminifera in the marly beds of the series²⁶⁷

has been questioned⁸⁸⁵ or denied, as they appear to have been derived, and occur in rain-wash material.

There are no Kirthar beds in the main part of the Range, and the Laki Series is followed by an unconformity, the Oligocene being entirely absent, the *Murree Series* of Miocene age succeeding the Laki in the eastern part of the Range; in the western part, however, the *Lower Siwalik* (Kamlial Stage) of fresh-water or estuarine origin rests upon the Eocene and is followed by the complete development of the Middle and Upper Siwaliks which continue the record into Pleistocene times.

(3) FATEHJANG AREA^{140 176 189}.—In the Punjab at Chharat, north-west of Fatehjang, the lowest Tertiary beds are massive limestones containing small nummulites, and passing upwards into gypsiferous sulphur-bearing chalky limestones with oil-seepages. The succession at Chharat, according to Pinfold¹⁴⁰, is at the base 'Hill Limestones' of Ranikot-Laki age, with mollusca⁴⁶⁰, followed by fresh-water shales, with *Planorbis* constituting the *Lower Chharat Stage*, succeeded by the *Upper Chharat Stage* of shales and limestones with nummulites. The mammalian remains from the Lower Chharat beds of the Attock district have been described by Pilgrim⁴⁶¹, and are of Middle Eocene (Lower Kirthar) age. According to Pinfold¹⁴⁰ the *Kuldana Shales* of Hazara are a continuation of these beds and agree in all respects with them. An unconformity separates the *Murree Series* of fresh-water origin⁷⁴ and about 8000 ft. thick in parts, from the Upper Chharats, and at its base there is the *Fatehjang Zone*, containing vertebrate remains and derived nummulites described by Pilgrim⁴⁶⁵. The whole *Murree Series*, which is correlated with the Gaj of Sind¹⁴⁰, consists chiefly of shales and sandstones. The *Murree* beds have a considerable development in the Punjab and Kashmir, and the whole succession is developed in Hazara.

(4) SIMLA AREA¹⁸⁴.—In the Simla area the Lower and Middle Tertiaries are known as the Sirmur Series, and this is divided into the **Subathu**, **Dagshai**, and **Kasauli Stages**¹⁴⁰.

The **Subathu Stage** is of marine origin and Middle Eocene age, and contains fossils of the Nummulitic beds. It is regarded as equivalent to the Kirthar and Laki Groups of Sind¹⁴⁰, and consists of a fossiliferous⁴⁸⁸ highly disturbed series of greenish grey and red gypseous shales, with bands of limestone and sandstone, and corresponds to the Hill Limestone and Chharat Series of other parts of the Punjab.

The **Dagshai Stage** consists of bright red nodular clays and grey or purplish sandstone, and is of the Flysch type. It is correlated with the Lower *Murree* of the north-west Punjab and is of Lower Miocene age.

The **Kasauli Stage** only differs from the Dagshai by the absence of the clays, for it consists entirely of sandstones, and has yielded a few plant-remains, including *Sabal major*, and corresponds to the Upper *Murree* beds, also referred to the Lower Miocene.

(5) KASHMIR.—In the Jammu Hills, Kashmir, the Subathu beds consist of shales and limestones considerably folded, and having at their base a seam of coal of variable quality⁷⁹; they pass up into the sandstones and shales of the *Murree Series*, which here has a thickness of over 8000 ft. In the Pir Panjal the Eocene consists of massive limestones containing nummulites and succeeded by variegated shales with coal-seams corresponding to the Chharat Series of the Punjab. The *Murree Series* is represented in the Punch State²⁵¹ in Rajputana.

The Lower Tertiaries of Kashmir and Ladakh have basic intrusions (peridotites) associated with them, and basic lavas and ashes also occur, as in Baluchistan; it is thought that the great basic lava-flows in the Central Himalayas⁶⁴ containing the 'exotic blocks,' which are of all sizes and of all ages up to and including Cretaceous, may have been poured out at the same time.

From the foregoing description it is seen that although marine conditions can be proved to have prevailed during Nummulitic times over a large area extending from Sind through the north-west portion of India, and along the foot of the Himalayas, as far east at any rate as Garhwal, yet there is a considerable difference in the development and character of the beds from place to place, according to the shallowness of the water and other local circumstances.

Orogenic Movements.—At the end of the Eocene the first of the Tertiary crustal movements took place which resulted ultimately in the upheaval of the Himalayas. The considerable folding and disturbance which then occurred reduced the area of the Tethys and shallowed the sea over large tracts, and in places completely excluded it, so as to lead to the formation of fresh-water instead of marine deposits, as in the case of the Sirmur and Murree beds.

(B) *Eastern Region*: ASSAM^{209 310 323 418 436 436a} —The shallowing of the sea above mentioned at the close of the Cretaceous is specially noticeable in the extreme east, where it is found to have begun at an earlier date than it did in the west. For in Assam the Nummulitic Series comprises scarcely any limestones, except in the Khasi Hills^{177 418 436 436a}, where the nummulitic limestone yields many genera of foraminifera as well as mollusca, diatoms, and *Liiothamnion*. This facies of the Eocene is largely spread in the Shillong plateau. On the other hand, in the eastern parts of Assam, in the Naga Hills, the facies of the lowest Eocene is argillaceous, consisting of the *Disang Shales* with thin bands of sandstone, correlated with the Ranikot and part of the Kirthar. Generally, together with the Miocene, deposits consists of sandstones, clays, shales, and thin coal-seams. The Cherra Sandstone in which the coal-seams occur is referred to the Lower Eocene^{177 274}. These beds in Assam are termed the 'Coal Measures'^{418 435 436}, and except for a few leaves are unfossiliferous, so that their precise correlation is uncertain^{72 85}. In many respects the upper parts resemble the Pegu (Miocene) Series in Burma, and similarly include a group of strata which yield oil (see below). The Coal Measures rest with an unconformity on the Cretaceous and older rocks. The lower formations which have been grouped⁸²³ into the *Jaintia Series*¹¹ and *Barail Series*, with thicknesses respectively of 3000 and 15,000 ft., are regarded as corresponding with the Middle Eocene to Lower Oligocene inclusive (Kirthar and Nari Stages). The *Jaintia Series* is richly fossiliferous¹¹¹ in places and consists partly of limestones. There is another unconformity separating these beds from the overlying formation of Miocene age which comprises the *Surma Series*, 13,000 ft. thick. This Surma Series extends from the Naga Hills to the Arakan coast and consists of sandstones, shales, and thin conglomerates, and corresponds to the Gaj Series (Lower Miocene) of Sind. In the Garo Hills^{168 310} it contains a rich marine molluscan fauna on certain horizons, and Mukerjee³¹⁰ considers the fauna to represent the Gaj of north-west India. The overlying *Tipam Series*^{85 485}, 12,000 ft. thick, consisting of coarse sandstones and clays, is believed to represent the Murree beds and the Lower and Middle Siwaliks, and it follows conformably on the Surma Series. The *Diking Series*, which is separated from it by an unconformity, is 5000 ft. thick, and is chiefly composed of pebble-beds. It is correlated with the Upper Siwaliks. These beds vary much in character and thickness locally, and are rarely fossiliferous.

BURMA^{68 70 71 73 75 84 96 145 160 162-165 169 175 195 199 212 215 255 256 318 319}
 354 355—In Burma^{160 199 817} there is a great horizontal and vertical variation in the lithological character of the Tertiary beds, and a different development in the north and south of the area due largely to the irregular and frequent advances and retreats of the sea up the gulf of deposition³²⁹. This has led to diverse local classifications and the employment of different names, so that the general succession and correlation of the beds have been matters of dispute¹⁶⁰
 164 167 175 199 318 329 854 355. The gulf in which most of the deposits were

laid down spread up between the Shan Plateau and the Arakan Yoma, and though there was a general retreat southwards of the sea during the period there were occasional short advances. This Burmese Gulf began as a geosyncline which deepened intermittently and suffered also some budding of its floor, producing minor folds and local unconformities. The result of all these incidents is that the Tertiary succession in Lower Burma differs considerably from that in Upper Burma, the marine beds mostly thinning out or disappearing northwards.

The Eocene in Lower Burma^{199 318 354} consists of shales and sandstones, with some grits and conglomerates, followed by marine shales and sandstones containing nummulites and having a thin nummulitic limestone at the top. Thin coal-seams in the Henzada district⁷³ occur in the series, which is considered probably equivalent to the Kirthar, Laki, and Pab Sandstone of India¹⁹⁹. North of Thayetmyo in Upper Burma the Eocene has a different development. Basal conglomerates, with a thickness in places of 2000-4000 ft., rest on highly folded schists, and are succeeded by shales and sandstones in three series which reach in the north a thickness in all of over 20,000 ft., according to Cotter, but thin rapidly southwards. Above these beds, which are of Lower and Middle Eocene age, there follow the *Pondaung Sandstones*TM which are referred to the Upper Eocene and consist of fluviatile sandstones and some variously-coloured clays reaching a thickness in the north of 6500 ft. The formation contains abundance of fossil wood and the earliest-known land mammalia⁴⁴⁷ in Asia, including perissodactyle and artiodactyle ungulates^{243 244} and abundant reptilian remains. In a conglomerate at the base marine mollusca occur. Succeeding the Pondaung Stage come the *Yaw Shales* or *Clays*, consisting of richly-fossiliferous clays with many nummulites and other organisms²¹², including the only typical mollusc *Velates schmideliana* of the Kirthar of Sind.* In the Pakokku district these clays are specially well developed. But the lamellibranch fauna is related to that of the Paris basin, and to those in Java and Borneo, and not to that of India, and Cotter²¹² held that Burma, Borneo, Java, and Sumatra constituted in Eocene times a zoo-geographical province distinct from that of western India as represented in Sind and Baluchistan. There is a great lateral change in the lithological character of the Yaw Clays, with a corresponding change in the fauna, and in the north of Minbu the formation contains coal-seams, and the marine deposits wedge out to the north and pass upwards into sandstones attributed to the Pegu System. The whole Eocene Series of beds in Burma had been earlier termed the *Bassein*⁶⁹⁹ or Nummulitic⁹⁶ Group, and part of the *Negrais Group* or *Chin Group* of deposits of a Flysch character is often included in the Eocene, for in the Arakan Yoma the characteristic foraminifera of the Laki beds, *Nummulites atacicus* and *Assilina granulosa*, have been found and in similar beds in the Andaman Islands.

Overlying the Eocene is the Oligocene-Miocene *Pegu Group* or *System*, consisting largely of dark greenish sandstones with subordinate clays and some thin carbonaceous layers. The beds vary much from place to place,

* *Velates perversus* (Gmel.).

furnishing clear evidence of the advance of a delta from the north into a land-locked gulf with marine conditions persisting longest in the south, so that in Lower Burma the succession is apparently somewhat different from that in Upper Burma. The term Pegu System is here employed in the sense which Cotter³⁵⁴ and Clegg³⁵⁵ proposed, so as to include the post-Eocene pre-Pliocene deposits. The Lower Pegu belongs to the Oligocene, and is separated from the Upper Pegu by an unconformity and palæontological break. The Upper Pegu division is referred to the Lower Miocene. The chief oil-bearing horizons are in the Lower Pegu, the Kama Clays being the main one^{169 173 175 255}. The names and correlation of the different stages here given are not universally adopted. But the Pegu System in the south has been divided by Vredenburg¹⁶² into six stages on palæontological grounds. And, according to Lepper, the lithological stages are in close agreement with them, though Stamp¹⁶⁰ denies this. The lowest stage is the *Shwetzetaw Stage*, chiefly of sandstone, about 3000 ft. thick, containing *Ampullina (Megatylotus) birmanica*, *Vicarya* sp., and species of *Batissa*. The *Sitsayan Stage* or *Padaung Clay* succeeds and consists chiefly of shales with *Lepidocyclina*, *Schizaster*, etc. This stage varies from 1500 to 3000 ft. thick. It is correlated with the Lower Nari. The next stage, the *Singu Stage*, consists of 1500 ft. of sandstones and corresponds to part of the *Prome Series* of Theobald⁹⁶. It is the main fossiliferous¹⁶⁵ horizon in the Singu oilfield, and is referred to the Upper Nari. The *Kama Stage* follows, and consists of shales alternating with shaly sandstones, reaching a thickness of 2000 ft., and containing numerous fossils^{162 165 195}. It is one of the most important beds in the Pegu System in both Lower and Upper Burma, and corresponds with the Lower Gaj (Aquitanian) of Sind. It yields a large fauna of marine mollusca, and some vertebrate remains⁴⁴⁷. Above it comes the *Pyalo Stage*, only in Lower Burma, containing *Ostrea latemarginata*. It is composed of sandstones, pebble-beds and shales about 1500 ft. thick, and is correlated with the Upper Gaj (Burdigalian), but it can hardly be separated from the Kama Stage. The highest stage has been called the *Akauktaung Stage*, and consists of grits, often red, and yellow sandstones, and contains *Ostrea gingensis*, *O. virleti*, and other mollusca. It is considered to be of Pontian or Vindobonian age, and was previously referred to the Irrawadian Series.

In Upper Burma the beds which correspond partly to the Kama Clays form the chief oil-bearing series²⁵⁵, and are of great thickness (9000-12,000 ft.). They vary much in composition, and alternations of sandstones, clays, and calcareous bands occur capriciously, the beds changing often in character and thickness or dying out laterally⁸⁴. A light blue clay is very characteristic, and gypsum crystals are abundant. There is a variable succession of clays, shales, sands, and sandstones, the alternations being frequent and the thicknesses irregular. Calcareous sandstones and arenaceous limestones occur, and are frequently fossiliferous. The beds of the Pegu System in *Upper Burma* in the oilfields cannot be satisfactorily correlated with those to the south in the Prome district. The succession in the several oilfields is local, and has been described for the four main ones: Yenangyang⁸⁴, Yenangyat³¹⁹, Singu¹⁶⁴, Minbu^{71 354 355} (see 'Economic Geology'), while Pascoe⁸⁴, Cotter⁸¹⁶, Evans and Sanson²⁵⁵ have given a general review of them. The invertebrate fauna described by Noetling¹⁹⁵ has been revised by Vredenburg¹⁶² in several papers. Fossils occur in the impure clays and calcareous sandstones, but the fauna is stated to be not constant in character on equivalent horizons, so that the so-called zones are only of local value. Near Yenangyat and Minbu^{854 855} the marine fauna in this Pegu series of beds contains many species of Oligocene or Lower Miocene age, which occur in corresponding beds in Java and Borneo as well as in Sind.

A terrestrial vertebrate fauna, similar to that in the lower part of the Siwalik System of the Himalayas, is also found in some of the upper beds of the Pegu Group. But where the Pegu beds are of fresh-water or brackish origin, and consist of sandstones with fossil wood, it is almost impossible to differentiate them from the succeeding *Irraioadian Group*, which in some places overlies them conformably, but in others unconformably.

It may be here mentioned that the variety of amber known as Burmite¹⁴¹⁸⁴⁷ occurs in these Pegu beds in the Hukawng Valley and elsewhere in Burma. It is found in a bed of blue clay, and is generally associated with bands of lignite¹⁷³.

The most important feature common to the whole Mekran-Pegu Group from east to west is that it contains petroleum^{169171173 175 214 255 316 319 320 354}. Moreover, in Baluchistan and along the Mekran coast, as well as in Burma and on the islands¹⁵¹ off this coast, we find groups of mud-volcanoes⁸⁴⁴ occurring in these beds in connection with the occurrence of oil (see 'Economic Geology').

In Assam²⁵⁴, in the Digboi oilfield, the petroleum is probably derived also from the same Miocene beds as in Burma (see 'Economic Geology').

BENGAL.—In the Chittagong⁸⁵ hill-range, eastern Bengal, there are beds apparently forming the extension of the Assam 'Coal Measures,' but containing typical Pegu fossils.

MADEAS.—Beds with a Miocene fauna having a Javanese facies, and including many species identical with those in the Burmese Pegu Group, have been found in a well boring at Karikal on the Madras coast. But with the exception of an outlier of Gaj beds, containing a rich marine fauna, at Quilon, Travancore, and the possible Miocene age of some of the Cuddalore Sandstones on the Coromandel coast (see p. 461), no other marine Tertiary beds are known in the Peninsula.

Orogenic Periods³²⁹.—Towards the close of the Middle Miocene there was a second great mountain-building disturbance affecting the north of India and Central Asia. This broke up the Tethys Ocean, and reduced it in places either to the condition of isolated lagoons or completely elevated its floor into dry land. The earlier rocks were folded and eroded before the deposition of the succeeding beds, which rest unconformably upon them. In the Simla area there is evidence of three great overthrusts, of which the main one took place after the deposition of the Subathu Series (Middle Eocene), according to Pilgrim and West^{184 397}. In the Punjab and north-west India^{140 176} these tectonic movements were conspicuous. The great overthrusts and overfolds in the Punjab, particularly in the Salt Range^{831864 383}, are a feature of primary importance in its structure, and they account for the present position of the Salt Marl and the previous misinterpretation of the succession of the beds in that area. It has been suggested that there was a primary thrust from the north in the Nummulitic-Siwalik interval, bringing the older rocks across the Saline Series. Later complex folding took place after the deposition of the **Murree** beds and the greater part of the Siwaliks, resulting in overfolding of the beds and further thrusts⁸⁹⁸. In the eastern Himalayas these later thrust-**planes** are conspicuous, affecting the Tertiary beds in Assam. No typical **marine** Pliocene beds are known in India, and the great bulk of the Upper Miocene and Pliocene deposits are of fluvial or terrestrial origin; they constitute the great Siwalik System in the Himalayas, and the similar series with local names in Assam and Burma⁶⁹. Probably in connection with the mountain-building movements in Middle Tertiary time there took place the intrusion of some of the great masses of granite, diorite, gabbro, etc., in the Himalayas and Baluchistan, while in Burma in the Arakan Yoma and

in the Henzada and Bassein districts there are intrusions of serpentine^{170 199} piercing the Negrais beds and the Nummulitios, which belong perhaps to the same period. In association with these Burmese serpentine intrusions are veins of steatite and the valuable jadeite. The jadeite^{200 347 388} occurs in albite-jadeite veins invading the peridotites and serpentine^{200 317 347 360}, but is chiefly obtained from boulders in a Pleistocene or sub-Kecent torrtial deposit in the river Uru in the Kachin Hills (*vide postea*).

(ii) Middle and Upper Miocene and Pliocene of Fresh-Water Origin.

Beds of this nature are practically restricted to the foot of the Himalayas and to the Irrawaddy basin. In the former they comprise the important Siwalik System, the beds of which follow on the Murree Series, and have been involved in the latest earth-movements of the Himalayas, resulting in a somewhat complicated system of folds, frequently overturned, and of overthrusts (see 'Tectonics'). In Burma the river Irrawaddy gives its name to the local development of this system.

HIMALAYAS.—The Siwalik Hills are a range of foot-hills separating Dehra Dun from the plains, but the formation bearing the name of the *Siwalik System*^{252 842 346} extends along the whole southern foot of the Himalayas and maintains a great uniformity of type in spite of local variations. It attains the enormous thickness of 16,000-20,000 ft., representing a long period of geological time and a continuously subsiding area of deposition. It consists of a series of sub-aerial and fluvial deposits²⁵³, mostly of the nature of alluvial fans or deltas and the gravel-sheets of river-plains, which are essentially similar to the modern materials deposited by the rivers now issuing from the Himalayan valleys on to the plains of Hindustan. Others may be of lacustrine²⁵² origin. The remarkable homogeneity and uniform character of the beds for long stretches, and the uniform structure of the formation along the line of strike are difficult to explain on the theory of their origin as alluvial fans and torrential deposits in connection with existing river-systems^{155158 425}, and a more probable explanation is that they were formed on great flood-plains by successive inundations of a single longitudinal river^{867 425}. In the trans-Indus region there is amongst them one conglomerate with peculiar characters which suggest glacial origin; it is known as the *Bain Boulder Conglomerate*²¹. It may be remarked that the petrological differences in the Siwalik beds are likewise ascribed partly to climatic changes²⁶². The Siwalik System has been divided up into zones by means of the mammalian remains which constitute the bulk of the fossils, but fresh-water shells, such as *Unionidce*", also occur. The beds comprise clays, sandstones, and especially conglomerates, and are famous for the abundance, variety, and remarkable character of their vertebrate remains, especially of mammals^{342 411 440 449}.

The classification and correlation of the Siwaliks have been matters of divergent opinions⁸⁶⁵, but the latest conclusions arrived at by Pilgrim^{69 489} on the evidence of the distribution of the mammalian remains are here adopted. The Potwar and Kangra-Hardwar areas are typical for the system³²⁶.

Where most fully developed, the Siwaliks fall into three divisions, Lower, Middle, and Upper^{68 69 346}, and in the north-west Punjab there seems to be a continuous succession of beds from the lowest Murree beds to the Upper Siwaliks^{140 326}. The Siwalik System as now correlated embraces beds from Middle Miocene to Lower Pleistocene.

The Lower Siwaliks are found in the Bugti Hills, as already mentioned⁴⁶⁵, and in Sind and the Punjab, and are marked by concretionary conglomerates, with calcareous nodular beds and clays, the whole coloured red and possessing a fauna comprising *Dinotherium indicum*, *Tetrabelodon angustidens*, etc. In Sind they are often called the Lower Manchhars, and in the Siwalik Hills,

Jammu, and Kangra, they have been called the Nahan Series, while in north-west Punjab⁸²⁶ the lowest part is known as the Kamliab beds¹⁴², which are about 900 ft. in thickness, and are succeeded by about 4000 ft. of red and grey shales, etc., forming the bulk of the Lower division, and containing abundant vertebrate remains which distinguish them from the lithologically similar Upper Murree beds.

North of the Salt Range the Lower Siwaliks pass up gradually into the Middle division, which thins out eastwards to the Jhelum. The Lower Siwaliks are generally correlated with the Tortonian (Middle Miocene).

The Middle Siwaliks, from 6000 to 8000 ft. thick, differ lithologically from the Lower, being softer and paler in colour, and contain pebble-beds. The fauna is also totally different, and the richest in the series. *Mastodon* and *Stegodon*, *Hipparion*, *Helladotherium*, and large antelopes are characteristic, and the whole assemblage is similar in type to that of Pikermi. The Primates are represented by several genera²⁴⁸ (*Palæopithecus*, etc.). A Pontian age is assigned to this division by Pilgrim.

The Upper Siwaliks^{346 442} consist of grey sandstones with conglomerates and boulder beds, and there is a gradual transition from the Middle division, but the fauna is quite distinct, and De Terra⁸⁵³ declares there is a complete break between the Middle and Upper divisions. They are traceable almost continuously from the Salt Range into the Siwalik Hills. The genera *Bos*, *Equus*, *Elephas*, *Stegodon*, *Camelus*, and *Jivatherium* are characteristic. More than half the genera still exist, but the species are extinct. The beds are regarded as mainly Pliocene, but embrace part of the Pleistocene. In thickness they reach 10,000 ft.

The thickest conglomerates are developed in the neighbourhood of the larger existing rivers where they issue from the mountains, and the character of the deposits agrees with that of the alluvia now being laid down. These facts suggest that not only was the mode of their formation similar, but also that the topography and course of the rivers had been previously established. It must be noted that though the series of deposits from the Nari to the top of the Siwaliks is, broadly speaking, continuous, yet sedimentation was not uninterrupted, so that Pilgrim recognises six periods of 'orogenic intensity' during their accumulation.

The Boulder-conglomerate beds at the top of the Siwalik^{213 346} Series are of Pleistocene age and reach their maximum development in the tract of country extending roughly from the Beas to the Chenab, attaining a thickness of over 5000 ft. in Jammu and Kangra, where the boulders also are of the largest size. Pilgrim¹⁵⁶ would place these beds in the lowest Pleistocene, but the formation of the Siwalik Series continued probably without any break from Pliocene to Recent times, except (according to De Terra⁸⁵³) between the Middle and Upper divisions. The conglomerates are believed to have been deposited in a rock-basin formed by a dam of upheaval across one or more great rivers fed by numerous tributaries *bringing down their loads of coarse debris from the lofty mountains to the north*. All the Siwalik beds are older than any of the deposits of the Gangetic plain. The topmost gravels of the Boulder Conglomerate which, according to De Terra^{346 353}, corresponds to the second Himalayan glaciation, contain human artefacts of pre-Chellean type, associated with extinct species of *Elephas* and other mammals.

BUBMA.—In Burma⁸⁴ there is a great series of fresh-water beds in the basin of the Irrawaddy consisting mainly of sands and soft sandstones, with some

' Pilgrim modifies this statement (*Journ. Asiat. Soc. Beng.*, New Ser., xv., p. 87 (1910).—E. H. P.

beds of clay and ferruginous and calcareous concretions, the whole in some places reaching a thickness of perhaps 10,000 ft. This is known as the **Irrawadian System or Series**. The lowest beds are regarded as belonging to the Middle Siwaliks (Pontian), and yield *Aceratherium*, *Hipparion*, etc.⁴⁴⁷, while the fluvial deposits of the Upper portion of the System are correlated with the Upper Siwaliks. At various horizons fossil wood is extraordinarily abundant, and fragments of silicified tree-trunks^{199 398}, sometimes of large size, also occur⁸⁴. The Lower Siwaliks are considered by Pilgrim⁶⁹ to be represented by part of the marine Pegu Series—Shwezetaw Stage—and estuarine beds containing *Dorcatherium birmanicum* occur about 1200 ft. below the top of the latter.

The Irrawadian Series rests locally with a slight or marked unconformity on the Pegu Series, and the boundary bed here is an old soil consisting of a brick-red clayey sand. But there is usually a marked break in the succession.

Throughout the whole Siwalik System the mammals⁴⁴⁷ are the predominant feature of the vertebrate fauna, but reptilian remains also are found, including chelonians (*Colossochelys*) and crocodiles (*Gavialis*). Invertebrate fossils are very rare.

In south-east Burma there are deposits of late Tertiary oil-shales¹⁷⁵ which are well developed in the Mepale basin; the fossil plant-remains in them indicate a Pliocene age, and the fresh-water mollusca belong to extinct species³⁹⁵.

ASSAM.—It is probable that the 'Tipam Sandstone'^{185 435} of Upper Assam, which overlies the Tertiary coal-measures and oil-bearing horizon and is closely similar to the Irrawadi Sandstone of Burma (containing similarly silicified wood), is of Lower and Middle Siwalik age, while the conglomerates of the Dihing Series, which succeed the Tipam, are attributable to the Upper Siwaliks.

COROMANDEL COAST.—Along the east coast of the Peninsula there is a series of loose sandy and gritty beds, occasionally argillaceous, with some bands of conglomerate and sandstone. These beds, which rest unconformably on all the older deposits, are known as the **Cuddalore Sandstones**, and pass beneath the low-level laterite and alluvium of the coast, ending westward in a scarp 100 ft. high. They contain much silicified wood, some of the tree-trunks being of large size, and some patches abound in marine gastropods. It is thought that these beds belong to the Pliocene, but, as above mentioned, some may be older. A similar series of deposits is found on the coast of Travancore, but are of fresh-water origin.

Tertiary and Post-Tertiary Igneous Rocks in Burma⁴⁷¹.—Igneous activity commenced in Eocene times^{198 199 317 389} and is widely scattered, lasting at intervals till Recent times³⁶⁶. The chief centres of activity are situated along a line stretching from the Myitkyina area through the Mingin Range west of Wuntho to the explosion craters on the Lower Chindwin^{199 236 366 389} through the Shinmadaung Hills in the Pakokku²⁵³ area and Mount Popa^{199 825} to the Pegu Yoma and beyond the coast to the volcanic island¹⁹⁹ of Narcondam and Barren Island (see chapter on 'Islands in Indian Ocean') and farther into Sumatra. A subsidiary parallel line runs through the hill ranges east of Monywa. Another line runs along the western edge of the Shan Plateau and to the rhyolites and tuffs in Thaton^{199 429}, and to the islands of Maingyi, Elphinstone, and Medaw¹⁹⁹ in the Mergui Archipelago off the coast. The igneous rocks are not all of the same character or composition in these different localities²⁴⁵. Thus in this second line the rocks in the Male-Kabwet area²⁰¹ consist of olivine basalts, but in the Thaton area, and also in the

islands, they are rhyolites. In the Monywa area they are devitrified rhyolites and quartz-porphyry, much like those in the Thaton area. The Lower Chindwin area^{199 286 866} has olivine-basalts as the commonest type, but there are also liparites, andesites, and ultrabasic rocks as well as tuffs, and some of the basalts contain nepheline³⁸⁶. In the Shinmadaung hills the rocks include basalts, andesites, and rhyolitic agglomerates. In the Pakkoku district²⁵⁸ the volcanic rocks are of late Cretaceous or early Eocene age. In the Myingyan district Mount Popa^{199 325}, over 5000 ft. in height, consists of lava-flows, tuffs, and agglomerates of Pleistocene to sub-Recent date. The later lavas are olivine-basalts and hornblende andesites; the earlier lavas and tuffs are rhyolitic. In the Pegu Yoma^{199 386} there are intrusive dykes and sills of post-Peguan and probably Pliocene age. Mount Loimye^{198 199 360} in the Kachin Hills in the Myitkyina area, which is composed of basalts and andesites with associated tuffs and agglomerates, having its basal aqueous tuffs interbedded with Tertiary sediments, began its activity in early Eocene times. The volcano of Loi Hai Hun, in the Northern Shan States, consists of a plug of columnar basalt with radiating dykes in Tertiary sediments, and appears to have been active in post-Tertiary times¹⁹⁹, like the Teng-Yueh volcanoes in south-west Yunnan. The island of Medaw¹⁹⁰, in the Mergui Archipelago, is in the same line as these Yunnan volcanoes, and as Loi Hai Hun, and consists of olivine basalt.

Tectonic Movements of Late Tertiary Times.—Between the Siwaliks of the Himalayas and all the older beds to the north with which they are found in contact there occurs one of the most striking features of Indian tectonic geology. It is known as the 'main boundary fault,' and probably runs the whole length of the Himalaya from Assam westwards to the river Beas or farther. It forms the northern boundary of the Siwalik System, and is of the nature of a reversed fault, the older beds (including the Eocene, Oligocene, and Miocene limestones of the Punjab) having been pushed southwards over the younger ones by a thrust from the north, so that their order of succession is inverted. Frequently there are also several thrusts and reversed faults⁸⁰ of minor extent parallel to (and south of) the main one and to the outer boundary. The Siwaliks are not found in any continuity north of the main fault, and, with the exception of one or two 'windows,' no outliers have been discovered in the higher hills, so that the whole system is more or less restricted to a definite zone. It has been held that the main boundary fault must therefore mark an original limit of deposition⁴, and cannot have been formed long subsequent to their accumulation, and that the southern limit of the Himalayas was defined by it at the commencement of the Siwalik period, while continued subsidence took place in this 'fore-deep'⁸¹ in which the Siwaliks were being deposited. The successive faults of the same nature would mark likewise successive limits for the newer formations as the foot of the Himalayas advanced southwards. But in the eastern Himalaya the theory of such sucoessional reversed faults does not seem to apply.

The southern boundary of the Siwaliks is also a fold or fault,

the Recent alluvia of the Ganges and other rivers resting unconformably up against an anticline or on steeply tilted or even inverted Siwalik beds. The great Indo-Gangetic plain to the south appears to have itself suffered gradual subsidence since Pliocene times (see below), though its origin probably dates back to the breaking up of Gondwanaland. The great Himalayan 'fore-deep' now represented by this plain extends eastwards from the Salt Range to the Shan Plateau, a distance of 1500 miles, and no borings have yet reached down to the floor of this immense depression, which is now filled with fluviatile deposits. It is one of the most remarkable structural features of India. It has been suggested that it is of the nature of a syncline, or even of a rift-valley, but this seems improbable.

The geodetic evidence^{5 47} 133-135 seems to confirm the generally accepted view that the Indo-Gangetic depression is a broad basin and is shallow on the outer side, but slopes gently inwards towards the Himalayas, from which it is separated by a steep wall resulting from a series of reversed faults¹⁵³.

The late Pliocene, or Pleistocene, orogenic movements which constituted the third and final phase in the building of the Himalayas²⁹⁷ and threw the Siwalik beds into folds are intimately connected with the determination of this fore-deep and with the formation of these reversed faults. The direction of the folds and fault-lines follows approximately the margins of the old land-mass to the south. In the Garhwal area³²¹ there is the 'Krol thrust,' which, in a 'nappe,' has brought the pre-Tertiaries southwards to rest directly on the Siwaliks, and also the 'Garhwal nappe' which is superposed on the Krol nappe, and is the result of several thrusts bringing schistose rocks to rest on Gondwana beds. Some of the movements along these thrust-planes are later than the deposition of the Upper Siwaliks. In the eastern Himalayas in eastern Nepal and north Bengal there are also two main dislocations which probably belong to the same earth-movements, one thrust causing the Gondwanas to lie on the Siwaliks, and the other bringing the Pre-Cambrian Daling Series to rest on the Gondwanas. In the Salt Range the overthrust has brought the Saline Series directly on to the Cambrian³⁸³, as previously mentioned.

At the eastern end of the Himalayan ranges and of the Indo-Gangetic fore-deep we find the Burmese fore-deep^{18 160 186 199 329 343}, which is at right angles to the Ganges Valley, and runs down to the Bay of Bengal. The two fore-deeps show considerable analogy, and it is probable that both the great thrust-movements which accompanied their formation proceeded simultaneously, though not **uninterruptedly** or from the same direction, the Burmese one being directed from the east and the Himalayan from the north. The

combination of the two compressional movements has determined the trends of the main orographic features, as well as the anticlinal folds and strike of the rocks in the Assam and eastern Bengal region, so that they all tend to assume sigmoidal curves.

In late Cretaceous and early Eocene times in Burma the Arakan Yoma was uplifted together with the Shan Plateau and the eastern hill ranges of Burma. These movements occurred at about the same period as the break-up of Gondwanaland and the intrusion of the masses of serpentine in the Burma-Nicobar region, and perhaps the granites of Tenasserim and the Malay Peninsula were intruded at the same time. But the chief movements which affected the area were post-Miocene¹⁸⁶ and resulted in the folding of the beds of the Pegu System. A still later period of disturbance affected the beds of the Irrawadian System, while in post-Pleistocene times there was elevation of the valley of the Irrawaddy and of the coast-line³²⁹. De Terra⁴⁰⁸ has especially investigated the late movements in Burma, and has traced the relation of the present surface-features to the geological history of the country⁴⁴³.

It has been maintained by some geologists that at the western end of the Indo-Gangetic plain the Himalayan fore-deep bends round and runs in a general southerly direction at the foot of the Afghanistan and Baluchistan ranges, and finally turns again north-west to run up the Persian Gulf into Mesopotamia. But this view is open to question. There is, however, a definite syntaxis³⁸⁴ at the north-western end of the Himalayas where the folds affecting them make a sudden and sharp bend to the S.S.W., forming the frontier ranges separating Afghanistan and Baluchistan from the Punjab and Sind. According to Davies³⁶⁸ the Kohat district is the pivotal point for the change in the orogeny, the axes of the ranges bending round here to run southward, and the Cretaceous-Eocene beds changing from an east and west strike to a north to south strike, accompanied by faulting. A somewhat similar sudden bend in the orogeny is found at the eastern end of the ranges in Assam and Upper Burma.

Origin and History of the Himalayas^{145 176 182 297 321 328 407 470}—

The whole history of the Himalayas as a mountain system⁴ is practically confined to Tertiary times as previously mentioned, though there are undoubtedly signs of earlier periods of considerable folding and disturbance, accompanied by the invasion of masses of igneous rocks. But it must be remembered that the granites of the Himalayas^{276 359} belong to several distinct and widely-separated periods of intrusion, and that some occurred up to, if not during, part of Tertiary times. Firstly, at the end of the Cambrian there was apparently local upheaval and exposure to erosive agencies

(e.g. in Spiti). But the three main phases of mountain-building which led to the production of the present chains took place entirely in the Tertiary period. Incidental reference has already been made to these crustal movements in describing the formations. The first was at the end of the Eocene, the second in the Middle Miocene, and the third in the Middle or Upper Pliocene. The first phase, though it extensively folded the Eocene and underlying older strata and uplifted them to a considerable extent, was not sufficient to obliterate the Tethys, which had been an area of marine deposition since Permian times, though it now became shallower in many parts. The second phase led to the main upheaval of the chain ; it folded and upraised all the other beds, including the Flysch deposits of Mekran (Miocene) age, and the ancient ocean was then divided up into isolated seas or lagoons. By these movements the mountains of Baluchistan on the west and of Burma on the east were uplifted as well as the Himalayas, and the main mountain ranges and drainage-lines were determined. A long belt of subsidence along the northern edge of the old Gondwanaland accompanied this mountain building, and formed a geosynclinal or vast faulted trough composed of two parts, one along the foot of the Himalayas, and the other more complex and composite one along the present course of the lower Indus. The buckling and trough-forming movements were not confined to one period, but went on intermittently till Recent times, and may not even now have ceased. The third phase comprises the Siwalik and post-Siwalik group of movements, which may be said to have begun by the gradual subsidence of the fore-deep during the formation of the Siwaliks and by the initiation of the reversed faults. The horizontal thrust from the north which now affected all the beds led to the dislocation of the crust and the repeated pushing of the older over the newer rocks.

The last orogenic movements affecting the Himalayas which occurred in late Pliocene or Pleistocene times resulted in overthrusts and overfolds with reversed faults. By this final group of movements the Himalayas attained their maximum height.

The Himalayas as a whole may be regarded as geologically composed of three belts : (1) the northern or Tibetan belt, consisting of rocks ranging in age from early Palaeozoic to early Tertiary ; (2) the Middle or Himalayan belt, composed almost entirely of Archaean and Pre-Cambrian rocks, with some Palaeozoic beds in a few places. This belt includes the great Himalaya having the highest peaks ranging from 20,000 to 29,000 ft. ; and (3) the sub-Himalayan belt which consists of Tertiary and largely Upper Tertiary fresh-water deposits forming the Siwalik hills. Structurally these belts differ greatly from each other, and the central one is imperfectly known. The structure of the north-western part of the range,

especially in the Punjab, has been more studied in detail than other parts, and has been variously interpreted' 140 145 176 182 297 883 384 446, particularly that of the outer Himalayas or foot-hills. The north-eastern parts are imperfectly known⁴⁷⁰. According to Wadia¹⁴⁵ 297 470 the western Himalayas may be divided into four structural zones with different types of structure. The outer, or Sub-Himalayan ranges, constitute 'the *Siwalik Zone*' in which the Jura type of folds prevail, with locally an orthoclinal type, the steep side facing the plains and often faulted. The second, or '*Sirmur Zone*,' consists of compressed isoclinal folds. These two compose the Foreland and consist of Middle and Upper Tertiary beds. The third, or '*Autochthonous Fold Zone*,' comprises the Carboniferous-Eocene belt, in which recumbent folds of Eocene rocks have cores of Carboniferous-Trias beds. The fourth zone is the '*Zone of Nappes*'⁴¹⁰, which may be divided into three belts, and in which the reversed strike faults became thrust-planes. Two main thrusts and nappes have been recognised in the Simla¹⁸⁴ Himalayas, the Krol nappe²⁴², and the Garhwal nappe. In Kashmir and to the north more nappes and thrust-planes have been traced. Along these more or less horizontal planes of thrust the older rocks have been pushed over the younger in a southward direction, producing great complication in the structure, and reversing the normal arrangement and succession of the beds. The sedimentary basins of Hazara and Kashmir lie between the crystalline axis and the Nappe zone, and only show normal open anticlines and synclines, according to Wadia¹⁴⁵. The crystalline axis of the Himalayas is very imperfectly explored^{394 399}, but we know that the folds are there more complicated and densely packed, and igneous intrusions of more than one period have added to the difficulty of interpretation²⁹⁷.

The structure of the northern flanks of the Himalayas is only partially known^{145 394}, but it seems to be of a simpler type than that of the southern slopes. Isolated portions, such as Nanga Parbat⁴³⁴ 437 have been investigated, and this mountain is found to consist partly of biotite gneiss with subordinate calc-, mica-graphite-, and actinolite- schists, and some bands of crystalline limestone, all much contorted. These are traversed by various acid and basic intrusions, including gneissic granite and epidiorites, and by a later (post-Permian) hornblende granite. Some at least of the metamorphic rocks are of Pre-Cambrian or even Palaeozoic age, and the Sakhala Series occurs at the foot of the mountain. The structure seems fairly simple, though the beds are folded and no nappes have been detected; Misch⁴³⁷ declares that the Permo-Carboniferous rests on the gneiss without a break.

Geophysical work³⁷⁶ in recent years has demonstrated many sub-surface structures, such as the existence of Burrard's 'Hidden

Range crossing the Indian Peninsula from W.N.W. to E.S.E. in a gentle curve parallel to the Gangetic Plain, with a trough to the south of it and another to the north of it underlying the former basin of the Tethys. The crustal structure lines³⁷⁶ of India and Burma showing the 'up warps,' 'down warps,' and crests and troughs of the 'Hidden Range' are clearly shown in Chart VII of the Geodetic Report, 1939, Survey of India.

The uplift of the Himalayas continued after the advent of man, as shown by his artefacts in some of the raised terraces of gravel⁴⁰⁷. Similar late Pleistocene and Recent movements have been shown in the same manner to have occurred in Burma^{408-408c} and Kashmir⁴³² (see below). Climatic changes⁴⁴⁴ accompanied some of these movements. There are some signs that the upward movement is still going on ; for the desiccation of the Tibetan lakes has been thought to be due to the continued uprise of the mountain range so as to impede the passage of the monsoon winds ; and the frequent earthquakes¹⁴⁶ indicate readjustment in the crust, while the rejuvenation of the streams by the increase of their gradients, which is seen in the cutting through of the recent alluvium in the lower valleys by the streams, suggests an uplift of the watershed (*vide postea*).

The succession of structural types²⁰⁹ in the mountains is remarkably displayed in the N.W. Punjab, where there is a gradual passage from the complex folding and overthrusting of the northern Tertiary limestone ranges into the low-dipping Sohan Basin and the complicated structure of the Salt Range¹⁴⁰. The Salt Range has been regarded as initiated³³¹ by the formation of a broad anticlinorium which apparently began^{368 383} before the end of the Laki (Eocene) after the emergence of the western end of the Himalayas which cut off the Kohat-Potwar basin and, in conjunction with an orogenic movement in Waziristan, isolated this area, forming a region of deposition. In later Tertiary times it rose again, accompanied by crumpling and overthrusting from the north-west, carrying Palaeozoic and Mesozoic beds over the earlier Tertiaries along a gently inclined thrust-plane as was explained by Zuber³⁸³, Anderson¹⁷⁶, Weller¹⁸², and others⁴⁷⁰, but this is disputed by those who hold that the Salt Marl is of Cambrian age. Wadia⁴⁷⁰ explains the structure of the Salt Range as a disrupted monocline, the severed upper limb of which has overridden and completely obliterated the southern limb. Weller⁴⁰⁷ regarded this overthrust to have taken place not in Miocene times but at the close of the Eocene, and to have pushed the Cambrian over the Tertiary Saline Series.

Pleistocene and Recent Formations'

(1) *Fluviatilis*.—The fresh-water deposits of the Indo-Gangetic depression cover an enormous area, and are chiefly fluviatile in origin, forming the confluent river-plains of the Ganges, Indus, Brahmaputra, and their affluents.

The older beds (the *Bhangar* of the Ganges Valley) are chiefly clays, and the younger are gravels or silts. The younger alluvium (*Khadar* of the Indus and delta of the Ganges and Brahmaputra) is mostly found near the present channels. The alluvium contains concretionary nodules or masses of carbonate of lime known as *kunkar*, which are especially abundant in the Bhangar, and also pisolitic limonite. Some of these alluvial deposits may date back to Pliocene times. The older alluvium of the Ganges in Bengal and the United Provinces contains extinct species (*Elephas antiquus*, extinct species of *Ehinoceros* and *Hippopotamus*, *Equus namadicus*, etc.), and usually occupies a higher level than the younger, which gradually passes into Recent accumulations.

That there has been a progressive subsidence and Recent movements at the foot of the mountains after the main post-Siwalik upheaval is proved by the thickness of this Recent alluvium in the Indo-Gangetic plain; at Lucknow a boring of 1000 ft. showed no signs of a rocky floor or of marine deposits, and at Calcutta a bore reached a depth of 481 ft., and was still in Recent fluvial deposits.

In other river valleys there is sometimes distinguishable an older and a younger set of alluvial deposits. Thus in the Narbada¹⁸¹ and Tapti Valleys there is a valley-trough which is in places 500 ft. below the level of the present river, filled with reddish clay and beds of sand and conglomerate, and containing an abundant fauna of mostly extinct species of mammalia (including *Elephas antiquus*), together with reptilian remains and shells of existing fresh-water mollusca. Only one of the mammalia is now found living in the Indian region. Contemporaneous with these extinct species are the earliest traces of pre-historic man⁸⁵³, in the shape of implements belonging to the Chellean Stage. In the upper valley of the Sutlej in Ngari Khorsum there are huge deposits of boulders, clays, and sands resting horizontally and unconformably on tilted Pliocene beds, and containing bones of Pleistocene mammalia; in Kashmir similar beds occur. No important disturbance, therefore, seems to have affected these parts, at any rate, of the Himalayas since Pliocene times.

In Kashmir the late Tertiary or Pleistocene deposits, known as the Karewas⁴⁸², which were laid down in lakes, consist of fine silts and clays with sand and gravel as a rule round the margins of the basins. They lie usually in horizontal beds, but locally have been much uplifted and tilted, as in the Pir Panjal, where they have been raised thousands of feet in a Recent elevation of that range. The beds contain fresh-water shells⁴⁶⁴ and leaves and wood of Recent species of trees. De Terra⁸⁴⁶ considers that these Karewa beds correspond to three inter-glacial periods. On the north-east Panjal slopes the beds are said to have a thickness of 5000 ft. A correlation with the other terrace systems of southern Asia, especially in connection with the glaciation of Kashmir and north-western India²²⁰, has been suggested by De Terra^{886 408}, as well as the connection of them with human prehistory⁸⁵⁸.

In Upper Burma post-Tertiary fresh-water and sub-aerial deposits are represented by the Plateau Gravel and Plateau Red Earth. The former varies much in coarseness, and, according to Pascoe, seems to have been derived mostly from the conglomerates of the Irrawadian Series, but it passes laterally into the red clayey sand forming the Plateau Red Earth. In the Northern Shan States the late Tertiary deposits are represented by the Lashio⁴²¹ and Namma⁴¹² coalfields⁴⁸⁰, in which lignite seams of importance from 1 to 33 ft. thick occur in association with sandy clays, silts, sandstones, and conglomerates. In the Southern Shan States the late lacustrine deposits have in places been crumpled by the solution of the underlying Palaeozoic limestones.

The gem gravels of Mogok^{246 431} are chiefly lacustrine deposits of Pleistocene and Recent formation, and some human artefacts occur in them^{408 408a}.

Rubies are the chief precious stones for which they were worked, but many other minerals are associated with them⁴⁰⁵. In river terraces also in the valley of the Nam Pai to the south-west of Mong Long the gravels have yielded some rubies and tourmalines¹⁹⁹.

In the Myitkyina district^{245 347} there are torrential fluvial conglomerates of Pleistocene or Recent age, of which the 'Uru Boulder Conglomerate,' which rests on Tertiary sandstones, is the most important, for it contains the boulders of serpentine or peridotite holding the jadeite veins. The other boulders in it consist of rocks of all ages and sizes imbedded in red earth. The whole deposit may be 1000 ft. in thickness^{317 350}. In the Hukawng³⁴⁷ Valley this conglomerate is well known. A detailed account of the Pleistocene deposits in Burma has been recently given by De Terra⁴⁰⁸.

In the Amherst district^{169 175} there are shallow basins of late Tertiary sands, clays, and shales, containing some plant-remains¹⁶⁹ and fresh-water mollusca³⁹⁵ belonging to extinct species. Oil-shales, occasionally rich, occur in this and the Mergui district¹⁹⁶. These beds may be of Pliocene age^{169 175}. In the Mergui district the Tenasserim Valley and other valleys have argillaceous and arenaceous lacustrine deposits with some lignite; in some places these deposits reach a thickness of 500 ft.

(2) *Sub-aerial: (a) Laterite*.—The deposits of laterite^{82 116 117 124 314 369} are very widely spread on the surface in the Peninsula, and vary much in thickness and composition. In its usual form it is a porous and argillaceous rock more or less impregnated with iron and varying in colour from white to yellow, red, or brown. It may be hard or soft, and sometimes has a brecciated appearance, while it is often traversed by small winding tubes. The surface has a characteristic pitted or scoriaceous appearance. In composition it ranges from a bauxite to a sandy clay or gravel with a high percentage of iron. The high-level laterite is usually richest in alumina, and has marked relations to the underlying rocks; it ranges from 50 to 200 ft. in thickness, and is chiefly developed on the Deccan plateau and on the traps. The low-level laterites are chiefly of a detrital nature, and fringe especially the west coast, but they also occur on the east coast; they rest indifferently on older beds of all kinds. The black cotton-soil or Regur of the Deccan and other parts of the Peninsula is attributed to prolonged surface-decomposition of the traps and other rocks, but the materials are mixed with a large percentage of organic matter. In the region of the Salt Range³⁶² alternating beds of loess and conglomerate spread over large areas.

(3) *Marine*.—Of Recent or Pleistocene marine deposits one of the best known is the **Porbander Stone** or 'Miliolite' of Bombay, which is a finely oolitic freestone largely composed of foraminifera. It is only partly marine in origin, being largely an aeolian deposit of calcareous sand, and shows characteristic false-bedding. In thickness it reaches 200 ft., and has been much used for building purposes. It extends on to the Tertiary rocks and Deccan traps in western Kathiawar. Raised beaches and sea-cut shelves round the coasts of the Peninsula point to Pleistocene or Recent elevatory movements. But in places, as in the submerged forest of Bombay, there is evidence of subsidence⁴⁵⁶. The Rann of Cutch was caused by a sudden depression of about 2000 sq. miles of the land to a depth of 12-15 ft. as late as 1819, while a smaller area was raised at the same time.

(4) *Caves*^{199 237}.—Cave-deposits have not been found in many places. But many caves occur in the Kurnool limestones, and at Billa Surgam one has yielded a mammalian fauna⁸⁸, some of the members of which are extinct, while others are closely allied to, or identical with, living African forms. The caves and fissures in the limestone of the Mogok area^{408b} in Burma have yielded

many extinct species of mammalia and species of fresh-water mollusca^{408c}. In Tenasserim the limestone hills near Moulmexn contain many **well-known** oaves, but their floors have not been systematically excavated, and there are several caves in the neighbourhood of Kalaw as well as in some other parts of the Shan States⁸³⁷. The age of the limestones is probably Permian, but may be Pre-Cambrian in some cases.

(5) *Glacial*^{89 145 220 472}.—Traces of a colder period in Pleistocene times have been found in the mountain regions¹⁴⁷, and evidence of this descent of the ice to lower levels is distinct in Kashmir (including the Pir Panjal) and Kumaon Himalayas²²⁰. In many of the Himalayan valleys old moraines are found as low as 7000 ft., whereas the present limit of the glaciers is from 11,000 to 13,000 ft. Near Dalhousie an ancient moraine occurs only 4740 ft. above sea-level. The present glaciers are in many cases but shrunken remnants of those which formerly existed. In the Punjab⁴³¹ there are erratic boulders scattered over wide areas, and they were probably transported by ice. Old moraines occur in other parts, and there is a kind of boulder-clay on the Potwar plain between the Salt Range and the Rawalpindi district which contains huge boulders and pebbles in a clayey matrix and was probably formed by fluvio-glacial agencies⁴³¹ during the Ice Age. The possible interpretation of the Karewas of Kashmir³³⁵ as being fluvio-glacial deposits, has been above noticed and regarded as marking three inter-glacial episodes. De Terra³³⁶ recognised four glacial periods in Kashmir, but it is remarkable that Cotter²²² found no evidence of any glacial period in the Attock district.

But since the movements of the continental ice-sheets of higher latitudes have chiefly been recorded in regions near the Equator by changes in the humidity, the evidence which is available is of a different nature⁸⁹. For instance, the desiccation of certain areas may be connected with the retreat of the ice and a decreased rainfall, and the older alluvial deposits⁸⁹ in the valleys and plains show by their position, relative height, and characters that they were laid down under climatic conditions different from those now prevailing. Arguments for a glacial period have also been drawn from the sudden disappearance of the Siwalik fauna, and from the present distribution of living animals and plants.

The development of the drainage system of the Himalayas and the carving out of the valleys and gorges are intimately connected with these meteorological changes, but more especially with the upheaval of the range^{86-88 145 155 156 367 368 392 407} so that it is certain that in that some of the main surface-features were developed in pre-Siwalik times (see above). The origin of the rivers^{367 368 392} in many cases goes back to early Tertiary times^{155 156}. According to Pascoe's views³⁸² the Eocene marine gulf, which extended from Sind northwards as far as Afghanistan and then curved round to the east and south-east through the Punjab to the neighbourhood of Naini Tal, was succeeded on the retreat of the sea by a great river (Indobrahm) which flowed west and north-west along the foot of the Himalayas as far as the north-west Punjab where it turned south and followed much the same course as the present Indus to the Arabian Sea. Two rivers flowing south into the Bay of Bengal cut their way back and abstracted the eastern affluent of this Indobrahm river, one capturing the Assam headstream and thus forming the lower part of the Brahmaputra, the other working back to the north-west and successively capturing lower portions of the proto-Indus till it reached the Jumna, thus forming the Ganges and reversing the direction of drainage. The Kashmir head of the Indobrahm, at the same time as it was losing its eastern affluents, was cutting back and capturing the westerly-flowing streams in Tibet. There were many northward-flowing streams from the edge of the Peninsular remnant of Gondwanaland which, during this whole period, flowed down into

the geosynclinal or faulted trough at the foot of the Himalayas and helped to fill it up with their alluvial deposits, and to give the present characters to the Ganges Valley. Prashad⁴²⁵ has further discussed the history of the Indobrahm river. The gaps through which the Gangetic drainage reached the sea, and those by which the rivers of the Punjab^{368 892 407} flowed to the Indus were probably initiated by earth-movements, and the secondary ranges crossing the main axis of the Himalayas obliquely influenced the general westward trend of the valleys. Stream-erosion continued during and after the uplift of the mountains was established, and worked along these structural lines. According to Pascoe¹⁵⁵ the Tertiary foot-hills of the Himalayas were successively formed in four or five parallel zones by successively produced reversed faults, north of each of which was land at the time of its formation, so that the hydrographic line was continuously advanced southwards.

According to Davies' view^{368 392} the Narbada, Godavari, and Mahanadi rivers originated in pre-Cretaceous (Gondwana) fault-troughs, and the Upper Indus arose from the overflow of a great lake behind the north-western Himalayan axis which rose across the marine channel.

In the case of the Irrawaddy River, Stamp²¹⁵ has traced its development, and according to his view a great Tertiary river flowed southwards into a long synclinal gulf in Eocene times; this proto-Irrawaddy was at first supplied by the water of the Tsangpo and ran through the Hukawng Valley; the upper part of this early Irrawaddy was formed by the Chindwin. The headwaters were subsequently captured by the Brahmaputra. A smaller parallel gulf to the east was formed by a subsidiary synclinal fold and was invaded by the sea in Miocene times, holding ultimately the Sittang River. Post-Pliocene warping separated the Upper Irrawaddy from the Sittang and led it into the Lower Irrawaddy. The Chindwin above Kalewa flows in a strike valley, but below that place it crosses the strike of the folds several times till it swings round the north end of the Mahudang Range to run south-south-east again.

(6) *JEolian*.—The Rajputana Desert, or Thar, is a wide expanse of wind-blown sand over an area 400 miles long and 100 miles wide. The sand-dunes, which strike as a rule transverse to the prevailing winds, rise in the south to a height of 400-500 ft. The origin of the desert is due to the small rainfall and the action of the south-west monsoon winds, the material being derived from the mechanical disintegration of the solid rocks now beneath the surface and covered up by the sand. The alkaline or saline lakes of Sind⁸¹³ amid the sand-dunes, and the Rann of Cutch, which is a silted-up arm of the Arabian Sea and now a saline marshy plain, are likewise due to desiccation since the Pleistocene. In the north-west Punjab west of the Indus and in the Salt Range³⁶² as well as in much of Baluchistan, there are widespread deposits of loess and much wind-blown sand of Pleistocene or Recent age.

Thermal Springs^{145 150}.—The distribution of the numerous hot springs in India appears to be connected in many cases with the position of important tectonic lines, especially lines of fault, but the question requires much further study. The thermal and mineral springs in India occur mostly in the mountainous regions, as in the foot-hills of the Himalayas. Some are sulphurous, others chalybeate, while some are radio-active, as near Bombay.

(7) *Volcanic*.—The Volcanic rocks of Pliocene or Pleistocene age which occur in Burma³⁴⁷ have been described above. These Burmese volcanoes belong to the 'Malay arc,' and the line is continued southwards into the Bay of Bengal by the volcanic islands, Narcondam³⁸⁷ and Barren Island⁸⁸⁷, which thus connect them with the Andaman Islands.

In India no Tertiary or Recent volcanoes are known, but in the far western region at the opposite end of the Himalayas we find the extinct volcano

Koh-i-Sultan in the Nushki Desert of **Baluchistan, and other examples in the** adjacent parts of Persia. The lavas, ash-beds, **and** agglomerates **which** occur here are of an andesitic nature, and the eruptions apparently lasted till Recent times⁸⁰.

Mud-Volcanoes.—The so-called mud-volcanoes of Minbu^{344 354 385} and of the Arakan Coast, such as those on the islands of Ramri and Cheduba¹⁵¹, have no connection with igneous action⁸⁴, but are due to the escape of gas from the petroleum deposits in the Miocene rocks, the mud and rock-fragments being disintegrated country-rock through which the gas, which is often accompanied by saline water, has passed. The outbursts are often violent and of an explosive nature, and the mounds of mud which are built up on the surface are frequently conical in shape and have usually a crater-like depression at the top.

Earthquakes^{146 400 404}.—The chief earthquake zone is along the foot of the Himalayas, being the region where the most recent orogenic movements connected with the mountains or foothills have taken place. Some of the quakes appear to be due to the slipping of the rocks along a fault or thrust-plane; others seem to have originated through excessive strains of the intensely-folded beds below the Gangetic basin.

ECONOMIC MINERALS^{125 141 171 173 214}

(Only some of the most important minerals and their principal occurrences are here mentioned.)

Coal^{90-92 125 141 249 269 270 294 320}.—The Permian coalfields (Gondwana System) produce 96 per cent, of the annual output of coal. The Tertiary fields of Eocene and Miocene age are comparatively unimportant.

Gondwana System.—It is only in the Lower division, in the Damuda Series, that coal-seams of economic importance are present²⁴⁹. The principal coalfields of this age are situated in the following provinces :—Bengal, Bihar, Orissa, the Central Provinces, Central India, and the Nizam's Dominions. The most important are those of Bengal, Bihar, and Orissa, known as the Giridih, Raniganj, and Jharia fields.

The Raniganj field²⁷⁰ covers 500 sq. miles ; it has faulted boundaries on all sides except on the east where the beds pass under the alluvium. Coal occurs in the lowest stage (Barakar) in four seams (=69 ft.), and in the upper (Raniganj) stage in at least ten seams (=110 ft.), but much of it is poor in quality.

The Jharia field²⁶⁹ forms a shallow elliptical basin, and the coal-bearing area covers about 150 sq. miles. Coal occurs in the Barakar and Raniganj stages. Much is of poor quality.

The Giridih field is 11 sq. miles in area, and yields excellent coal from the Karharbari seam.

There are many other prospective fields in Bengal, Bihar, and Orissa, covering about 500 sq. miles in all.

In Central India there are several fields in the Rewah Basin, with a total area of 2000 sq. miles. The Umaria field¹⁹⁴ is being worked, and is of special interest from the occurrence of the marine fossiliferous band¹⁹⁴, in the Barakar stage.

In the Central Provinces the coalfields lie in three apparently separate basins, i.e. (1) the basin of Satpura²⁹⁶ and Chhindwara in the north-west; (2) the Sarguja and Chhattisgarh in the north-east (being the south-east continuation of the Rewah Basin); and (3) the Godavari Basin extending into Madras on the south-west. They cover several thousand square miles and comprise many distinct coalfields. In the case of the Godavari Basin much of this very large area is probably buried under the Deccan trap.

Tertiary Fields.—In Assam the coal-measures are of Cretaceous and Tertiary age (see p.), and the fields fall roughly into two groups—(1) a belt along the north-east frontier⁴³⁵ extending for some ninety miles, and (2) scattered fields in the Khasia, Garo, and Jaintia Hills. The most productive coalfield is at Makum⁴³⁶, and another in the neighbourhood of Jaipur^{436 a} contains ten seams of coal.

The Burmese fields, of Tertiary age^{199 430}, yield a small quantity of coal of poor quality.

In the northern Punjab⁴⁷⁵ there are Eocene beds of coal in two principal seams, one at the base of the Eocene in the trans-Indus range forming the Makarwal seam, and the other the Dandot seam, also in the Lower Eocene, in the eastern half of the Salt Range³⁶⁴. These beds are below the marine Nummulitics. The coal is of inferior quality. In Kashmir and Jammu the coal is likewise poor.

Rajputana furnishes lignites of little value, in association with Nummulitic rocks.

In Baluchistan the seams are thin and the rocks are much disturbed, but they have been worked at the Khost colliery.

Petroleum³¹⁶.—The occurrence of petroleum in India is confined to two areas of folded rocks at opposite ends of the Himalayas, **and** is associated with Tertiary beds. At the west end there is the Punjab - Baluchistan area which is continued into Persia, and at the east end is the Assam-Burma area, extending southwards into Java, Sumatra, Borneo, and New Guinea.

In the western area the natural conditions for the retention of the oil are not so suitable as in the eastern, for in Baluchistan the folded strata have been either broken by earth-movements or their edges truncated by denudation, so that much of the oil has escaped. Oil-springs occur in the Punjab^{161 332 364 476} in the Rawalpindi district and farther to the south-west, but the output is **small**. **According** to Preiswerk¹⁶¹ the oil comes from the contact **zone**

between the nummulitic limestones and the younger gypsciferous marls of the Upper Nummulitic, as in Persia. The Potwar region is the chief one where oil-shows occur in the Laki Series and in the basal beds of the Murree Series. But the oil is now chiefly obtained from the Middle Tertiary³⁶⁴. In the *Attock district*^{222 332} the oil-bearing beds are the Nummulitics, and the Chharat Series (Kirthar) consisting of limestones and shales, is the chief source; in each case anticlines in the beds are the sought-for structure³³². There are oil-shales also in the Salt Range^{227 381c} of probably Tertiary age.

In Baluchistan near Moghal Kot in the Sherani country where oil-springs occur, the saddle of the anticline exposes porous strata which have been worn away to form the gorge of a river, and the oil has thus run to waste.

In Burma^{84 169 265 316 317 354 355} the conditions⁴⁷⁶ are mostly favourable, the beds being folded into anticlinals or domes, and consisting of alternations of porous sands and impervious clays belonging to the Pegu Series. These often rise as small hill ranges through plains of Irrawadi Sandstone and alluvial deposits. The trend of the folds is usually N.N.W.-S.S.E., but varies slightly. As previously described, the Tertiary³¹⁶⁻³¹⁹ beds were deposited in a geosynclinal trough between the Shan Plateau on the east and the Arakan Yoma on the west. This gulf, which was at first a shallow inlet of the sea, was gradually filled up in the north, from where the greater part of the sedimentary material came, so that the sea retreated southwards, and fluvial and estuarine deposits successively encroached, the whole area at the same time slowly subsiding. The occurrence of commercial petroleum is closely connected with this synclinal area. The oil-sands range^{173 255 316 320} from Lower Miocene in age in the Thayetmyo³¹⁸ district to the Middle Eocene on the borders of Pakokku and the Lower Chindwin, the older marine beds being to the north. Associated with them are gypsum, saline water, springs of sulphuretted hydrogen, gas-pools, and bituminous deposits, but the lignites usually mark a more fresh-water type of sedimentation, the petroliferous sandstones and associated beds indicating brackish water or marine conditions. The argillaceous sediments are the main source of the oil. In places, as at Yenangyaung, the structure is an almost symmetrical dome, but this simplicity is rare, and crushed and faulted anticlines usually introduce complications. Asymmetric anticlines, paired or reversed faults, together with the rapid change in the lithological facies and thickness of the beds and frequent thinning out of others, are common features in most of the oilfields. The correlation of the beds in different areas is therefore a matter of much difficulty, and each field has its special peculiarities, the fossil contents being usually

the only safe guide, as Vredenburg's^{162 165} and Cotter's²¹² papers have proved. The classification and correlation of the beds by Stamp^{160 167 477} differ from that usually given in the Geological Survey Memoirs, and are not here followed. The conditions determining the occurrence of oil in Burma have been discussed by Noetling, Grimes, Pascoe, Stamp⁴⁷⁶, and others.

In Burma the chief oilfields^{84 255 477} are those of Yenangyaung, Yenangyat^{319 477}, Singu¹⁸⁴, and the Minbu district^{354 355}.

In the Yenangyaung field⁸⁴ the rocks form an elongated elliptical inlier of Pegu beds about 6 miles long and 1 mile broad, surrounded by Irrawadi Sandstone. The direction of the axis is 28°W.-of-N.-28°E.-of-S., and the maximum dip on both sides of the crest is 35°-40°. A transverse oblique fold complicates the structure, and small cross-faults are associated. There are several oil-sands at different horizons, but they vary much in thickness and level. Gas and water are associated with the oil in the wells.

The Yenangyat³¹⁹ Hills are continued southwards by the Singu Hills on the other side of the river, and consist of a long inlier of Pegu beds, forming a single asymmetric anticlinal fold rising and pitching in three places, so as to form three domes and separate oilfields. The Yenangyat fold is not unlike one of Mrazec's *pli8 diapirs*⁸⁴ or 'pierced folds,' such as are found in the Red Sea oil-field according to Hume. The axis is not the same as that of Yenangyaung, and deviates less from due north and south. The dips are much steeper on the east than on the west, owing to the monoclinical character of fold. Several oil-sands at different depths are met with.

In the Minbu district^{354 355} the structure is that of an acute anticline slightly overfolded towards the east, the flexure having reached a more advanced stage than that of Yenangyat. The well-known Minbu mud-volcanoes³⁴⁴, as previously described, are due to the violent emission of gas accompanied by mud and water; they occur mostly along a straight line which seems to be a fault with an anticlinal fold. The mud is derived from the blue clays of the Pegu Series.

Many other petroleum localities are known to occur in Burma, and in the islands¹⁵¹ of Ramri and Cheduba lying off the coast, and in the Baranga Islands, oil, gas, and mud-volcanoes are associated, as at Minbu. In the Amherst district there are oil-shales^{169 175} forming the chief member of a group of late Tertiary beds (described above) comprising subordinate beds of sandstone and thin limestones. Only fresh-water gastropods³⁹⁵, plant-remains¹⁶⁹, and teleostean fish have been found in them; their precise age is doubtful, but they must be referred to late Pliocene or early Pleistocene.

The whole system of folds affecting the petroliferous Peguan

strata in these parts runs more or less north and south, and has been produced by a lateral movement from east to west, acting mostly during or after the Irrawadian period. The cross-folding seems to have been the result of the Himalayan movement.

In Assam^{85 214 254 316} and eastern Bengal the petroleum localities are limited to the basins of the Brahmaputra and Surma, and form a belt of country more or less parallel or concentric with that in Burma. Its southern end is connected with the oil occurrences on Ramri Island and other points in the Bay of Bengal. The petroliiferous beds belong to the Tertiary Coal Measures, and it is believed that they form parts of more or less overfolded domes or anticlines cropping out beneath the Tipam Sandstones, and separated from the older Disang Shales by a thrust-fault, to the west of which all the oil indications are situated. The succession of the beds differs in the north and south of the Assam-Arakan oil-region²⁵⁴, and the correlation of the various horizons is doubtful. The structure of each area also is different and is mostly complicated by overfolds and thrusts. The Tertiary succession and description of the beds have already been given (see p. 457). The Coal Measures of Assam are not unlike the Pegu Series of Burma, but are practically unfossiliferous.

The most important field commercially is the Digboi²⁵⁴ field at the northern end of the Assam railway, where the longer axis of the assumed asymmetric dome runs from E.N.E. to W.S.W., but the dips in the neighbourhood of the wells are southerly. The oil-sands in the Coal Measures are variable and inconstant, as in Burma.

Manganese^{16 92 214 320}.—Deposits of manganese of economic value are chiefly worked in the Central Provinces and fall into three groups :—(1) Deposits associated with a series of manganiferous intrusive rocks (the Kodurite Series) found in Madras ; (2) Deposits associated with rocks of Dharwar age principally belonging to the Gondite Series, typically developed in Balaghat-Nagpur area; (3) Deposits occurring as lateritoid replacement-masses on the outcrops of Dharwar rocks, of which the most important areas are in Mysore and Sandur.

(1) The Archaean Kodurite Series of igneous origin, which is typically developed in Vizagapatam, contains large bodies of manganese ore of irregular size and shape, chiefly composed of psilomelane ; probably they are largely of metasomatic origin.

(2) The rocks of the Gondite Series are probably of metamorphosed sediments of Dharwar age, and are characterised by the manganese-garnet known as spessartite and the manganese-pyroxene, rhodonite, mixed with quartz. The ore-bodies occur as lenticular masses and bands intercalated in the quartzites, schists,

and gneisses. The bands may measure several miles long, and are often well bedded parallel to the strike. The typical ores of the Nagpur-Balaghat area consist of mixtures of braunite and psilomelane. Sometimes the ores are associated with crystalline limestones of Dharwar age.

(3) The ore masses in this group are impure and of lower grade, for they range from manganese-ores to iron-ores, and have been formed by replacement at the surface of Dharwar schists, phyllites, and quartzites.

Mica⁹⁴.—All the known occurrences of marketable mica are practically limited to the Peninsula. Nearly three-quarters of the mica produced in India is contributed by Bihar and Orissa, for Madras contributes less than 25 per cent.

Muscovite is by far the most important of the Indian micas, though the other varieties occur in abundance. The mineral occurs in pegmatites associated with mica-schists, quartzites, and other schistose rocks of the so-called upper division of the Archaean Group, and is found in sheets or veins or lenses generally following the foliation-planes. The valuable mica-bearing pegmatites do not as a rule traverse the massive gneisses and granites.

In the Hazaribagh³⁹¹ district there seems to be a genetic connection between the dome-gneiss and the pegmatites.

Magnesite^{95 214 457}.—The 'Chalk Hills' in the Salem district are so called because of the network of white magnesia veins which occur in the ultra-basic rocks of which they are composed. The rocks are peridotites, chiefly of the dunite variety, being olivine-chromite rocks which have suffered mineral changes by which the olivine has been altered into serpentine and subsequently into magnesite. Unlike the surrounding gneisses into which these rocks have been intruded they have not suffered foliation.

Magnesite also occurs in Mysore, in Coorg, and in other districts as veins traversing peridotites.

Asbestos composes a narrow band at the top of the Lower Dolerite in the Cuddapah Series of Madras³⁷⁰, and is found elsewhere in India and Burma in small quantities²¹⁴.

Barytes.—This mineral is of some importance in the Madras Presidency²³⁵ and occurs in connection with the Cuddapah System.

Bauxite^{82 125 127 141 314 401}.—The highly aluminous varieties of laterite, consisting of nearly pure bauxite, are found in various parts of India, the richest areas being in the Balaghat and Jubbulpore districts in the Central Provinces. The alumina (Al_2O_3) ranges

from 51 to 65 per cent. Considerable deposits of bauxite have also been found in association with the Nummulitic Series of beds in Jammu and Poonch²⁵¹ States.

Gypsum occurs in enormous quantities in the Salt Range³⁶⁴ and its neighbourhood in association with the Salt Marl, and also in masses in the Spiti Valley in a pure condition replacing Carboniferous limestones.

Phosphates.—Phosphate in the form of apatite occurs in lenticular masses in the Dharwar rocks of Singhbhum³³⁴, and in the mica-pegmatites of Hazaribagh and in the mica-peridotites of the coal-field of Bihar. But in the Cretaceous (Utatur) beds of Triohinopoly it is found as concretionary nodules in large quantities.

Ofpiment, the trisulphide of arsenic, which is used for the yellow and red colours of lacquer, is mined in Chitral.

Salt'—Rook-salt occurs chiefly in the Punjab and North-West Frontier Province and in Mandi State in Tertiary beds. In the Salt Range of the Punjab^{120 364 426 426a}, the most important mines are at Khewra, where the salt is found in three main seams in the Salt Marl Formation, lying directly in one place beneath beds of Lower Cambrian age; but it is probable that they are of Lower Tertiary age, and owe their present position to an overthrust (see p. 453). Some potash-bearing⁴²⁵ seams are also here present. It has been suggested that this Salt Marl is of igneous origin, but it seems undoubtedly to be a sedimentary formation^{96a}.

At Kohat^{97 426} the salt is worked in open quarries, and in the anticlinal at Bahadur Khel it is seen to be at the base of the Tertiary System. The beds can be traced for a distance of about 8 miles, and have an exposed thickness of 1000 ft. Overlying the massive beds of rock-salt are greenish and reddish clays, gypsum, and thin nummulitic limestones, all of which are much folded and crumpled. The great thickness of the salt is one of its most remarkable features.

Sambhar Lake in Rajputana is one of the chief sources of the salt formed in regions of internal drainage; this lake fills after the monsoon, and by evaporation of the highly saline water the salt is obtained; but the sodium chloride is not pure, being mixed with sodium sulphate and sodium carbonate. There are many alkaline lakes in Sind³¹³ from which soda is obtained.

Steatite^{92 98}.—Steatite is widely distributed and largely worked in India, especially in Bihar, Orissa, and Madras. In the Jubbulpore district it is found imbedded in the limestones and schists of the

Pre-Cambrian rocks. It is associated with dolomite, from which it appears to have been derived by metamorphic action.

There is a large deposit of pre-Cambrian age in Idar State, Bombay Presidency, forming a bed over 200 ft. thick and over a mile in length, and it is associated with various other magnesian minerals.

In the Minbu district, Burma, where it occurs as veins in intrusive serpentine, deposits of this substance have also been worked,

. **Amber.**—The fossil resin, which Noetling³⁴⁷ termed Burmite, is found in blue clay belonging to the Lower Kirthar (Miocene) beds in the Hukawng (Hwekaung) Valley in Upper Burma^{416 474}.

PRECIOUS STONES³³⁷.

Diamond.—Diamonds occur in the Vindhyan conglomerates near Panna^{9 3a} in Central India. Here the chief stratum is seldom 2 ft. thick, and lies between the Kaimur and Rewa Series. The diamond is derived from older rocks, but its original home is as yet undiscovered. The most characteristic associated pebbles are of jasper derived from the Bijawar Formation and vein-quartz similar to that traversing the Bundelkhand granites. The neighbouring alluvium resulting from the disintegration of these conglomerates likewise yields the precious stones.

There is a southern group of occurrences of the gem in Madras in the districts of Cuddapah, Bellary, and on the river Kistna¹⁴¹, but in all these cases the gems occur only in the alluvium, though Purana rocks occur in situ in these areas. It is here that the Golconda diamonds have been obtained. In the Kurnool district the band of conglomerate at the base of the Kurnool Series is the diamond-bearing layer.

Ruby, Sapphire.—These are chiefly obtained in the lacustrine gravels from the detritus of the metamorphic Archaean (?) rocks of Mogok^{173 199 246 337 405 431} in Burma as above described (p. 418), but sapphires have also been found in a felspathic gneiss in the Zaskar Range, Kashmir.

Beryl³³⁷ occurs as aquamarine in the granite-pegmatites of various parts, especially in Bihar, in Nellore, in the Coimbatore district, and in Rajputana and Kashmir.

Garnets belonging to the almandite variety are worked in the mica-schists of Rajmahal, in Jaipur State, and in other places.

Spinel and precious varieties of **tourmaline**³³⁷ are obtained from the gravels in the Ruby Mines area in Burma²⁴⁶.

Jadeite, a silicate of sodium and aluminium, and belonging to the pyroxene group, occurs as a segregation layer or vein with albite in

serpentine intrusive into rocks which are believed to be of Tertiary age in several parts of Burma^{132 200 245 347 388}, especially in the Kachin Hills in the north. According to some geologists these intrusions are of late Cretaceous age.

Building and Ornamental Stones^{103 104 117 141 145}.—The Archaean and Purana¹¹⁷ rocks have furnished most of the building and ornamental stones in the past. The Kaimur Group of the Vindhyan System may be specially mentioned as having yielded valuable sandstones. Slates and limestones are obtained from the Cuddapah Series. The Deccan Trap and many other igneous rocks of various ages have also been used for building, and some types of laterite are employed for architectural purposes.

The Vindhyan System has furnished many limestones and ornamental marbles, and the Archaean rocks of Rajputana are famous for the Makrana marble of Jodhpur.

The Jaisalmer limestones of Jurassic age have also been worked for centuries, and Nummulitic Limestones in the Punjab yield marbles of several types. From the Bagh (Cretaceous) Series of the Narbada Valley there is obtained a 'coralline limestone' for building purposes, and the Gondwana sandstones in Bengal and the Central Provinces are also employed. In Kathiawar the milio-lite or 'Porbandar stone,' a porous oolitic limestone of æolian origin, is largely worked (see p. 469).

Gold^{17 214 333}.—Practically nearly all the gold produced in India comes from the Kolar goldfield in Mysore, where typical quartz veins occur in the Dharwar System, deposited generally along the foliation planes of the schists. The bulk of the schists are horn-blendic, and result from the alteration of basic lava-flows and ash beds, but there are also some banded hornstones and ferruginous quartzites. The schist belt is of lenticular shape and has been regarded as a synclinal folded into the granite-gneiss which is partly intrusive and later than the schists.

The veins, which are epigenetic in origin, are lenticular in shape, swelling out sometimes to a width of 30-40 ft. The principal vein in the field averages 4 ft. in thickness, and is payable for a distance of over 6 miles. Occasionally the veins are bent with the schists into acute folds, leading to the production of large ore-bodies along the axes of the folds. Chutes of pay-ore with a dip within the plane of the vein different to that of the vein itself are also a characteristic feature. Post-Dharwar dykes of diabase traverse the whole mining field.

In Hyderabad and in Anantapur, Madras, gold-bearing reefs in the Dharwar schists are also worked.

Alluvial gold in small quantities occurs in Assam³⁶¹, in Chota

Nagpur, in the Punjab, in the North-West Province in the gravels of the Indus River⁴⁴¹, and in Burma²⁶⁰, where the Upper Irrawaddy, Chindwin, and other rivers have been worked with small success.

Copper^{92 214}.—In the Singhbhum¹⁴¹ 334 district (Bihar) copper-ores occur as 'rather indefinite lodes interbedded with the Dharwar phyllites and schists,' but frequently the mineral occurs as small grains sparsely disseminated in the rocks. Below the surface the ore consists of chalcopyrite. The associated schists are chiefly varieties of muscovite- and chlorite-quartz schists with quartzite layers.

In Sikkim copper-ore also occurs, and is associated with bismuth, antimony and tellurium. The deposits are similar in origin to those of Singhbhum. The ores are disseminated in or interbedded with the Daling Series, which chiefly consists of phyllites, in places highly metamorphosed into schists and gneisses¹²⁹, and they occur chiefly in the neighbourhood of intrusions of granite. Copper occurs also in the Bawdwin Mines^{171 183 199 214} in Upper Burma in association with the lead-zinc-silver ores from which it is extracted.

Lead-Silver-Zinc Ores.—The chief centre for these ores is at Bawdwin^{93 106 171 183 199 214} in Upper Burma, where the ores occur as huge metasomatic bodies in connection with a zone of great disturbance affecting the felspathic grits and rhyolitic tuffs of Cambrian or Pre-Cambrian age (see p. 421).

The main ore-channel is at least 8000 ft. long and probably 400-500 ft. wide, and within it several lodes have been found. It is bounded by two main parallel faults which are earlier than the formation of the ore-bodies, but there are also other faults of later date.

The chief ores are galena and zinc-blende intimately intergrown, but some copper occurs in one lode, and pyrite and chalcopyrite are sparingly distributed through the zinc-lead ore, which is also argentiferous. According to Coggin Brown, the Tawnpeng granite is intrusive, and is perhaps connected with the mineralisation of the faulted zone in the rhyolitic tuffs.

The galena deposits in the Putao⁴²⁷ area, which occur in metamorphic rocks invaded by masses of granite and other igneous rocks, are apparently of the same nature. In the Southern Shan States there are important lead-ore deposits in the Mawson area²³⁸ occurring in zones or filling up fissures in the Ordovician beds.

Iron 92 154 214 218 320 390.—in Bengal, Bihar, and some of the Eastern States²¹⁸, the ironstone shales between the Barakar and Raniganj stages of the Damuda Series are extensively worked, the clay-ironstone nodules furnishing the ore.

Practically all the other important iron-ores occur in the Vedic

(Archaean) rocks, especially in the Dharwar Series as in Bihar and the Orissa States²¹⁸, where the ore-bodies occur in banded-hsematite-quartzites. In Singhbhum^{334 390 401} the iron-ore series of the Dharwars is likewise of much importance.

The ore-deposits in Mayurbhanj State consist of roughly lenticular bodies of haematite with small proportions of magnetite in association with granites and charnockites. Banded ferruginous quartzites and quartz-rocks are intimately associated.

In the Drug district, Central Provinces, banded quartz-iron-ore schists and phyllites with occasional masses of pure haematite occur as lenses of apparently magmatic origin associated with ultra-basic rocks intrusive into the Dharwar schists, or as metasomatic layers or zones in the schists. The latter also include banded ferruginous quartz-rocks of the usual type which furnish a fair percentage of iron. There are many other important haematite deposits in Jubbulpore, Raipur, and Bilaspur^{145 214 320}.

Silver (see 'Lead').

Tin⁹² 143 171 173 199 219 241 415 In the Mergui¹⁹⁰ and Tavoy²⁴¹ districts of south Burma^{141 171 173}, and in some of the Southern Shan States⁴⁶⁹, tin ore (cassiterite) is obtained by washing alluvial gravels, but it occurs also in pegmatite intrusions and quartz-veins traversing the granites, and in other rocks of the so-called Mergui Series (see 'Tungsten'), as in the Malay Peninsula.

Tungsten^{92 143 171 190 199 219 241}.—Wolfram-bearing lodes occur in Lower Burma as veins, chiefly consisting of quartz, which traverse granites and the metamorphosed sediments of the Mergui Series, which is itself older than the granite. The wolfram-tin-bearing belt runs northwards from Mergui and Tavoy²⁴¹ into the Southern Shan States and beyond. One of the principal deposits is at Mawchi⁴⁶⁹ in the Karenni States. The wolfram and cassiterite lodes in Burma are all closely associated with an extremely acid granite of remarkably constant composition and texture intruded into the slates, argillites, clay-schists, silicified tuffs, etc., of the above-mentioned Mergui Series. The mineral is also largely obtained from the detrital and alluvial deposits in the same areas.

Chromite^{95 214 336 375} In the peridotites of Mysore and Singhbhum as segregation masses³⁷⁶ and in the 'Chalk Hills' near Salem, and in the serpentines of the Andamans and of Baluchistan, this mineral occurs. Its mode of association with these ultrabasic rocks presents no unusual features. In Ladakh large deposits are known in dunite intrusions.

Zinc.—The chief occurrence of zinc-ores is in the Bawdwin Mines in Burma, in association with lead and silver (see 'Lead').

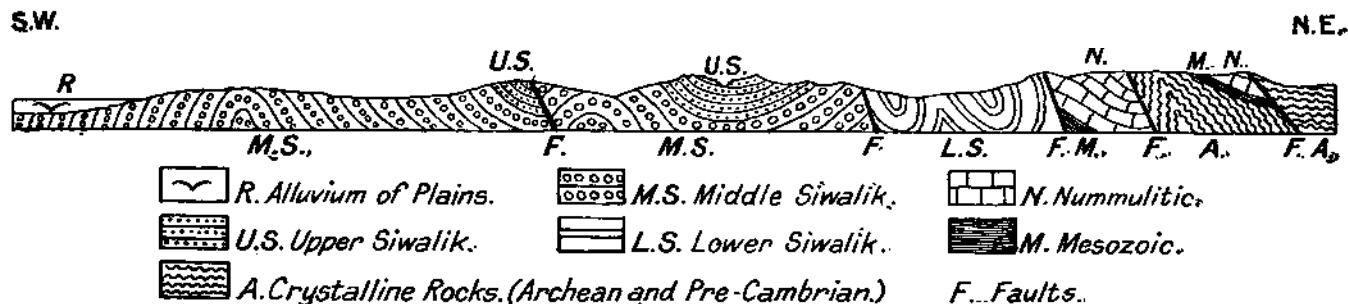


FIG. 18.—GENERALISED SECTION ACROSS THE SUB-HIMALAYAN ZONE SHOWING REVERSED FOLDS AND THRUST FAULTS AFFECTING THE SIWALIK AND OTHER BEDS (based on Sections by Middlemiss).

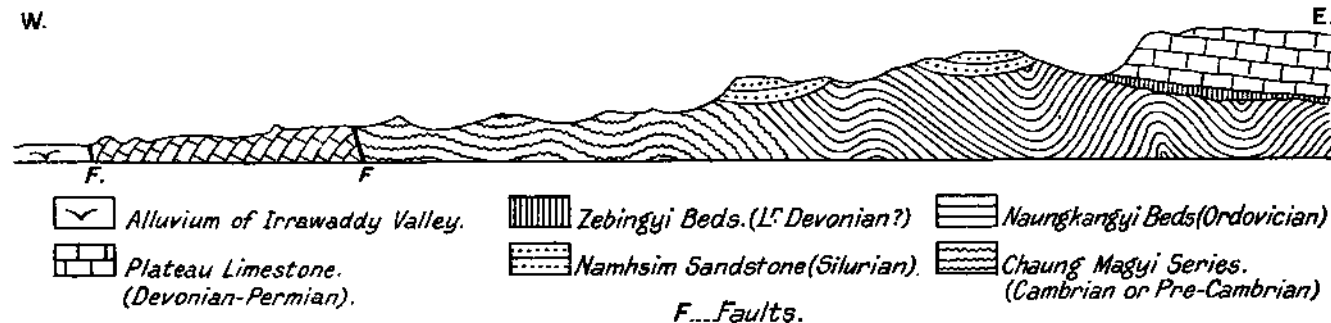


FIG. 19.—GENERALISED SECTION OF THE WESTERN SCARP OF THE SHAN PLATEAU (based on Sections by La Touche).

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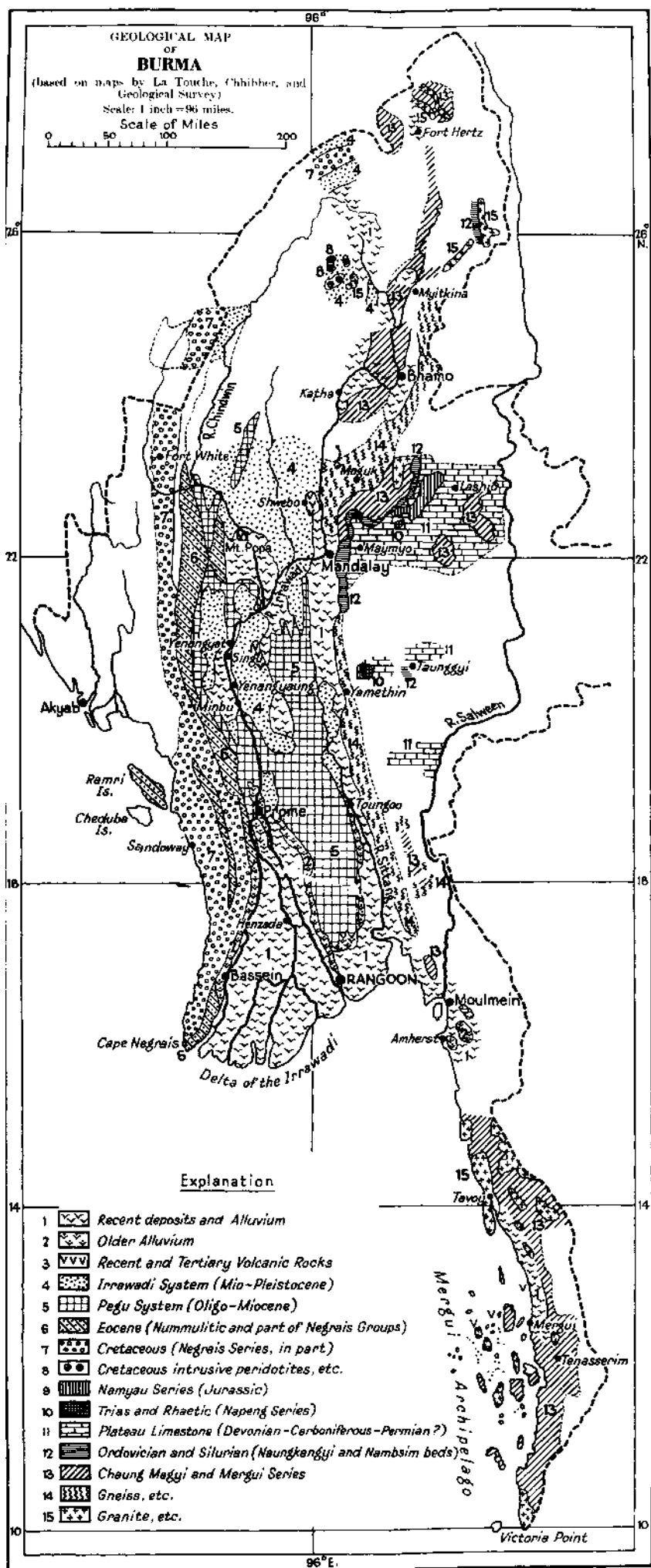


FIG. 20

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SECTION II.—CEYLON

General Character.—Ceylon^{22 26 31} is geographically and geologically divided into two sharply differentiated regions, the mountains consisting of ancient crystalline rocks, and the plains of Recent formations. The island is bordered by a low coastal plain which widens out in the north to occupy nearly half of the surface. This plain is cut in the Archaean rocks which compose the basement of the whole island, and it forms the first peneplain³⁵, which is 100 ft. above sea-level and is covered with later deposits. The central *massif* forms the southern and central portions of the island and consists entirely of Archaean or Pre-Cambrian rocks forming the surface. In addition to the first peneplain there are two other higher distinct peneplains, one at 1600 ft., and the other at 6000 ft. above sea-level. In the coastal plain to the south and east of the mountain mass rise numerous 'inselbergs,' such as the Sigiriya rock rising 600 ft. above the plain, in many of which caves exist. Wadia³⁵ has described in detail the three peneplains, and considers that the mural scarps are fault-scarps. The central *massif* of Ceylon is regarded as a special uplifted block of the nature of a horst, with a mean elevation of 6000 ft. The lowest or coastal peneplain is, in his view, the oldest, and of pre-Jurassic formation. The fact that the central block forming the uppermost peneplain does not possess a more mature topography and that nearly all the waterfalls over its precipitous edge are of youthful character³⁵, support Wadia's view of its late uplift. But Adams²², on the other hand, considered the coastal plain to be the youngest. A submarine plateau³⁸, about 200 ft. below sea-level and averaging 12 miles in width, surrounds the island, the sea-floor sinking rapidly outside it to a depth of 3000-6000 ft. ; on the north this plateau merges into the continental shelf surrounding the Indian peninsula.

There is a very close relationship between the geology of this island and that of the neighbouring part of India, for both are almost entirely composed of the same types of Archaean or Pre-Cambrian rocks, plutonic and metamorphic, and are fragments of the ancient Gondwanaland. Many of the gneisses are identical in character with those of the Salem district of Madras¹. Members of the Charnockite² series also occur, pyroxene-granulites being widely distributed. Normal granulites are also common. Occasionally the granulites are gneissoid, the foliation being due to a movement prior to final consolidation⁴.

As regards the composition of the gneisses there are acid gneisses with biotite or sillimanite, and basic gneisses with pyroxene and hornblende. Microcline- and anorthosite-gneiss have also been

observed, and crystalline limestones are frequently of importance, and are intimately interbanded with the gneisses. Amongst the many types of intrusive plutonic rocks are granites, pegmatites, diorites, gabbros, quartz-norites, and serpentines, while dyke rocks are rare¹⁴.

A classification of the crystalline rocks which form the basement of most of the island was proposed by Coomaraswamy^{5 8} as follows :—

- (3) Charnockite Series or granulites.
- (2) Crystalline limestones.
- (1) Older gneisses (Ortho-gneisses).

The fullest and latest description of these crystalline rocks, which practically constitute the whole of the island, is that given by Coates³¹, who recognises two main groups of gneisses which he terms the *Bintenne Series* and the *Wanni Series*, with the *Khondalite* and *Charnockite Series* forming two other minor groups. This classification replaces that proposed by Coomaraswamy^{5 8} and Adams²².

The predominant rock of the *Bintenne gneisses*¹ in the Bintenne country between the hills and the sea at Batticaloa is a banded black-and-white gneiss. The white bands are composed of quartz with some felspar, and the black bands mainly of biotite with iron-ores. There are also numerous fine-grained whitish unbanded varieties. A wide band of limestone associated with garnetiferous granulites occurs on the south flank of the Kataragam hills. The strike of the gneisses varies, but at Batticaloa it averages E.-W., swinging round northwards to N.E.-S.W., and thus conforming with that of the Khondalite-Charnockite series. Biotite gneisses are found also in many other areas in the island.

The *Wanni gneiss group*, which comprises reddish-pink or buff-coloured gneisses and granulites of intrusive appearance, occupies the northern³⁰ half of the island, spreading over the low country from the east to the west coast around the northern edge of the mountain zone. The chief member of the group is the Tonigala gneiss in the Kurunegala district. Near the coast it loses its gneissoid structure. Pink orthoclase felspar and microcline with some quartz and magnetite grains compose a common variety. Some parts of the rock consist only of quartz and orthoclase or microcline. In the Kalkudah-Nilaveli area the rocks contain monazite and magnetite. The Ambanpitiya gneisses form long parallel bands in the Chamookite Series. The Wanni gneisses have been compared with certain rocks in the North Arcot district of India³¹. Monazite is conspicuous in these gneisses.

The *Khondalite Series* consists of schistose and gneissic rocks of which quartzite or granular quartz-rock several hundred feet thick

is its principal member, with fissile quartz-schists, finely banded quartz-felspar-gneisses, crystalline limestones, and a peculiar garnet-sillimanite schist. These rocks occupy the greater part of the central hill-zone and extend in a narrow band to Trincomalee. A rare variety (not found *in situ*) is a corundum-silimanite rock. The crystalline limestones are more or less dolomitic and contain various accessory minerals, chiefly silicates. The marbles are exposed along the Matale-Dambulla road. The garnet-silimanite rocks are well seen along the Passara-Namunukula road, while the quartzites have their greatest development near Trincomalee, forming hill-ranges and headlands on the coast. The whole series represents metamorphosed sediments.

There is another group of gneisses which Coates³¹ calls the Kadugannawa gneisses. These are characterised by hornblende, and are typically dense black rocks forming a lens about 30 miles long and 8 miles wide. Biotite and feldspars and especially calcite occur in them. They border the Khondalite-Charnockite hill country on its western side and form in places hill ranges. Diopside-scapolite rocks are interbanded with these hornblende gneisses. They are somewhat like the calc-gneisses of Vizagapatam in India.

The *Charnockite Series* is regarded as of igneous origin and intrusive into the older gneisses and schists, as in India. The more acid members of the group consist of granular rocks with the component minerals arranged in alternating light and dark bands of quartz and felspar with dark green or black pyroxene or hornblende; they vary in grain from a glassy-looking compact rock to coarse pegmatitic types. Microcline is very rare or quite absent, thus distinguishing the Indian type. The basic or noritic varieties of charnockite are rich in pyroxene, hornblende, or mica. They are most numerous on the eastern side of the charnockite area. An ultrabasic variety occurs near Balangoda. Garnetiferous varieties also are common and many others intermediate in composition. The Charnockite Series occupies the whole of the south-west quarter of the island, forming great intrusions several hundred miles in extent, with minor sills, interbanded with the khondalites. Leptynites and acid granulites, probably of intrusive origin, are associated. Pegmatites and basic dykes traverse all the rocks, the former being rich in uranium-bearing minerals.

The group of pegmatites which has its principal outcrop near Balangoda was called by Coomaraswamy¹¹ the Balangoda Group, and Adams²² used the same designation. The rocks are often very coarse in texture and the characteristic accessory mineral is zircon. Monazite, thorianite, and beryl also occur. The pyroxene-scapolite rocks of the Galle district^{22 31 34} are intrusive and vary considerably in composition, but are very rich in lime-silicates. They are

specially developed in the south-west of the island, and constitute the so-called *Galle Group* of rocks.

The bands or beds of limestone⁵ in the Khondalite Series, which have their boundaries parallel to the foliation of the surrounding gneisses and granulites, vary in width, coarseness of grain, structure, and mineral composition. Thus the proportions of calcite and dolomite are not constant, and the number and abundance of accessory minerals are subject to variation. Some of the calcareous rocks are typical dolomites, while others are cipolins. The most characteristic accessory minerals are olivine, diopside, phlogopite, apatite, spinel, pyrite, and graphite; less common are amphibole, clinohumite, magnetite, scapolite, sphene, and orthoclase. The origin of these limestones is a matter of dispute. The presence and character of these limestones give the crystalline series of rocks in Ceylon a striking resemblance to the Grenville Series of eastern Canada. Adams²² considers that these Ceylon limestones are undoubtedly altered sediments, and he recognises two important well-defined bands, known respectively as the Badulla and Matala bands from their place of occurrence, while a third development in the Rakwana district consists of a number of shorter bands. The quartzites are often interbedded with the limestones and are exposed at many places in the south of the island, as near Ratnapura and Passara. It is not clear how Adams' grouping of the rocks can be correlated with that of Coates, or of Coomaraswamy, and the order of succession of the groups seems to be a matter of uncertainty, though it is proved that the Charnockite group is intrusive, and therefore of later date than the gneisses.

The granulites², together with the charnockites, constitute the mountain *massif* of south-central Ceylon, and are intrusive in the older gneisses; they are specially characterised by mineral banding and variation in chemical and mineralogical composition, exhibiting all transitional stages from pure pyroxene-rocks to pure quartz-rocks. Near their junction with the limestones the granulites have produced contact metamorphism, and have developed new minerals⁵ rich in lime (scapolite, sphene, diopside, phlogopite, and calcite), and garnets frequently occur. The charnockites bear the same general characters as in southern India. One of the finest developments of charnockite is at Haputale²², where it is plainly seen as a great sheet intruded into the gneiss. In one place near Kandy corundum (sapphire) has been discovered *in situ*¹². Spinel and garnets are especially common in the granulites³. On the other hand, moonstones (felspar) occur in the pegmatites or graphic granites, as at Jatore, and intrusions of this character in the Charnockite Series carry numerous accessory minerals¹¹. But though these various crystalline rocks are the ultimate source of the gems^{22 25} for which

Ceylon is famous, it is from the drift-deposits that the precious stones are now almost entirely obtained. Dykes are extremely uncommon, apart from pegmatites, but one typical dolerite dyke runs near the eastern side of the island for at least 30 miles.

The graphite^{3 8 9 14 18 22 31 33 35a} which is of much economic importance, occurs in branching veins in the charnockites and gneisses, and also in scales and flakes in the rocks immediately adjacent to the veins. In many districts the main veins are parallel to the foliation-planes of the gneisses, thus striking north-west and south-east, but in others they make a considerable angle with the strike. In the Kurunegala district the veins run parallel to a system of joint-fractures at right-angles to the strike of the foliation. The veins vary in width from less than an inch to several feet. Numerous rock-fragments and inclusions, which are undoubtedly of secondary origin, occur in them. Quartz and pyrite are usually present, often forming a central band. Various theories^{9 10 14 33} have been put forward to account for the formation of the veins, such as the emanation of carbon monoxide or the reduction of liquid hydrocarbons *in situ*^{3 20}. The largest workings are at Ragedara.

Jurassic.—Upper Gondwana beds, containing plant-remains, have been discovered^{16 17 81 89} on the island at Tabbowa near Puttalam, and probably extend over considerable areas to the north of the mountain mass. The beds, which rest directly on the crystalline rocks, as in Madras, consist of argillaceous sandstones, grits, shaly bands, and thin nodular limestones, the total thickness being probably not less than 2000 ft., and they lie in a much-faulted syncline. The plants include *Cladopklebis reversa* Feist., *Cl. denticulata* Brongn., *Teniopteris spatulata* McClell, etc., and suggest a correlation of the beds with the Kota (Lower Oolite) beds of Madras^{31 39}. A carbonaceous older shale, in which the plant-remains have been converted into bituminous coal, or exist only as impressions, has been more recently discovered at Andigama²⁸.

Miocene.—In the Jaffna district, at the north end of the island, marine Miocene limestones of considerable thickness and highly fossiliferous have been discovered¹⁹. *Orbiculina malabarica* (Carter) which occurs in the Miocene of Travancore is found here, as well as many lamelibranchs and gastropods. In the Mannar and Anuradhapura districts similar limestones are overlain unconformably by an areno-argillaceous series. In the southern province⁸¹ at Minihagalkanda, 40 miles east of Hambantota, there is an outlier consisting of ferruginous grits and sandstones, followed by areno-argillaceous beds with nodular limestones, about 35 ft. thick in all, containing an abundant fauna, including *Clypeaster depressus* Sow., *Ostrea virlei* Desh., and many other mollusca. The majority of the fossils from all the localities in Ceylon resemble species from the Miocene of Sind or Cutch. In Dutch Bay in the North-West Province of the island, Miocene beds containing many marine fish-remains⁸² and some lamelibranchs and gastropods have been recently described. The presence of Miocene^{28 4} and Pliocene fresh-water deposits, though now very limited in extent and thickness, with the fossils mostly derived and mixed, has been proved in various localities by the occurrence of mammalian and reptilian remains.

Pleistocene and Recent.—Apart from the Miocene beds and the Upper Gondwana sandstones there are no post-Archæan rocks known to occur in the island, except superficial Pleistocene and Recent deposits of which the *gem gravels*²⁵ are the most important. These gravels²⁵ are specially developed in the Ratnapura district, and are accompanied by sands, grits, sandy clays, and leaf beds, constituting the *Ratnapura Series*³⁷. A fossiliferous horizon occurs immediately above the gem gravels and sands, and has yielded mammalian remains³⁷, some of locally extinct forms, such as lion and hippopotamus' together with living and extinct species of elephant. The deposit seems to contain a mixture of older and younger Siwalik species, and is partly derivative and re-deposited³⁷. Some of the species are of Miocene^{23 24}, but others of Pleistocene age.

The solid rocks are hidden nearly everywhere by a thick covering of laterite²². Raised beaches, shelly sandstones, and marine clays containing Recent molluscan shells, are present in coastal districts, indicating an elevation of about 20 ft. in the Hambantota district. The lagoons along this coast also point to positive and negative movements. Along the western shore of Ceylon there is a band of hard sandstone with streaks of ilmenite and garnet-grains which is exposed at low-water and is a cemented beach-deposit similar to the 'stone-reefs' on the coast of Brazil. In some parts they form bars or spits and run out to sea; in other places they are found some distance inland. Shore deposits of coral-debris occur along part of the south-west coast; and sand-dunes have been formed along much of the coast, and cover Mannar Island⁸¹.

Tectonic Features.—According to Adams²² the island forms 'a great syncline whose axis runs throughout its length in a general north and south direction.' The syncline is closed on the south, but is open to the north, plunging in this direction and disappearing beneath the Miocene strata. Several minor parallel folds are seen in the highlands in the south of the island, and in the extreme south-western region there is a low anticline. Wadia³⁵ recognises only one system of folding in Ceylon by which the Archæan and Pre-Cambrian rocks were thrown into a synclinorium trending N.N.W.-S.S.E. for the greater part of its length and occupying the centre of the island from Galle to Trincomalee. All subsequent movements were vertical epeirogenic upheavals, bounded by faults. The successive elevations^{22 27} of the island leading to the formation of the three penepains^{35b, 36} took place in pre-Miocene times, as the Miocene beds fill cracks and holes in the gneiss of the coastal plain.

The separation of Ceylon as an island must be referred to a recent stage in geological history. Recent movements^{31 32} are indicated by the presence of coral-debris on the coast, and by the raised beaches and lagoons above mentioned; in the caves²⁹ the Stone-age cultures are found. The coral-reefs of the Palk Straits and 'Adam's Bridge' are built up on the submerged plateau³⁸ connecting Ceylon with the southern point of the Indian Peninsula¹⁵, and are all of Recent or sub-Recent origin.

It is probable that there has been no complete marine submergence of the island since Archæan or Purana times, and that it has been

exposed to continuous sub-aerial denudation. The configuration of the country and direction of many of the valleys appear to have an intimate connection with the foliation of the crystalline rocks and the position of the bands of limestone. Thus the foliation-strike is usually from south to north or south-east to north-west, and valleys and ridges with a similar strike are often conspicuous, while jointing nearly at right-angles to the foliation has influenced the development of the minor features and tributary valleys.

ECONOMIC GEOLOGY

Graphite^{38 14 18 20 31 33 35}, the occurrence of which has been mentioned above is commercially the most important mineral. The vein-deposits are of three kinds :—(1) fissures filled with graphite, (2) lenticular segregations in gneisses, or (3) pegmatitic veins in which graphite is an accessory mineral with quartz and orthoclase predominating. No graphite veins are known to exist in the Bintenne gneiss area, but nearly all are in the charnockite area, and the mineral seems to have been derived from carbonaceous material. In southern India there is a similar association of this substance with charnockites and leptynites. Wadia³⁵ notices the frequent association of calcareous strata with graphite bodies, and refers to the various theories of its origin, but does not support the igneous theory that they arose from a deep-seated magma.

Precious Stones^{12 22 25 31 35}.—Alluvial gravels of more than one date yield nearly all the precious stones except moonstones. The varieties of sapphire are the most important stones in the gem gravels, but aquamarines, chrysoberyl, zircon, tourmaline, garnet, spinel, moonstone, and topaz occur. The gem gravels range generally from 5 to 30 ft. *in* thickness, but in places reach 100 ft. They occur chiefly in the great strike-valleys of the south-west of the island³¹. The gems have also all been found *in situ* in pegmatite veins. The gravels from which most of them have been obtained are in the Ratnapura district, constituting most of the Ratnapura Series.

Mica of the muscovite, phlogopite, and biotite varieties occurs in pegmatite veins or in contact zones with limestone. Near Balan-goda it has been worked in pegmatites.

Thorianite³⁵.—Rich deposits in alluvial gravels near pegmatites have been worked in the Ratnapura and Galle areas.

Monazite³⁵ is a constituent of the black sands on the west coast associated with ilmenite and zircon.

Iron.—The ore, consisting of haematite or limonite, was formerly obtained by the natives from the lateritic soil due to the decay of the underlying crystalline rock. Titaniferous sand occurs on the east coast.

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CHAPTER XI

ADEN AND THE PERSIAN GULF

SECTION I.—ADEN

General Characters.—Aden¹⁻³ consists of a small irregularly-shaped peninsula about 15 miles in circumference, connected with the mainland by a narrow sandy low-lying isthmus, north of which a sandy plain stretches inland for 35 miles to the foot of the hills known as Gebel Shiap. The British Protectorate extends inland to the Bana River and far to the east and west. The peninsula forms the eastern breakwater to the harbour, which is partly bounded on the west by another smaller mountainous promontory, Gebel Ihsan. A small island, Seerah, lies on the east side of the Aden Peninsula.

The total area of British territory is only about 75 sq. miles, but that of the Aden Protectorate extends over 112,000 sq. miles.

The town of Aden lies in a hollow usually described as the crater of a volcano⁶ and enclosed by precipitous heights, the loftiest point of which is Gebel Shumshum or Shamsan, 1775 ft. The heights represent the fragments of one or more volcanic cones of which parts of the outer walls alone remain.

Geology.—The volcanic rocks of which Aden is entirely composed belong to more than one period of eruption^{4 57 817}.

The oldest are lavas of an acid character, comprising rhyolites, trachytes, keratophyres, and these give the characteristic relief and main surface features to the peninsula. These rocks are well developed on the north flank of Gebel Shamsan. Coarse ashes, breccias, or conglomerates composed of these materials are intercalated between the lava-flows. The next igneous eruptions consist of phonolites in several varieties which are often of a reddish colour. Many of the trachytic and phonolitic rocks show points of resemblance with the rocks of the Rift Valley of East Africa⁸. Trachyte, obsidian, and pumice locally succeed them, but the next great flows of lava consist of basalts or basic andesites^{4 6}, which rest on and more or less cover up all the preceding rocks⁷, and are stated to be divisible into an older and a younger series. The eruptions probably lasted from Oligocene to Pleistocene or Recent times.

There are no sedimentary rocks on the peninsula, except a recent calcareous deposit containing marine shells all belonging to species

now living in the Gulf or Bay of Aden. This deposit occurs only on the north coast near Steamer Point, and is elevated 4-6 ft. above sea-level.

At the foot of Gebel Shamsan there are traces of several old sea-levels, and it is stated that high up on the sides of this mountain are still older marine beds filled with fossil shells. Well-sections on the sandy plain to the north show a series of beds of sand and gravel to a depth of 16-24 ft., and below them a conglomerate of rounded pebbles, 6-8 in. in diameter, mostly of volcanic and very rarely of metamorphic rocks.

ADEN PROTECTORATE

The country inland is only slightly known geologically^{6 9 17 17a}. But there is a basement of metamorphic and ancient volcanic rocks in the inland range of hills (Gebel Shiap¹), and this is here overlain by a limestone with inter bedded soft shaly bands. The limestone^{6 13} contains fossils, including *Parallelodon egeronianum* Stol. (found also in Somaliland and in the Spiti Shales of India), *Nucula cuneiformis* Sow., several species of *Perisphinctes*, *Behmnites*, *Trochus*, and *Nerinea*, which indicate an Upper Jurassic age^{6 13 17a}. Overlying these fossiliferous beds are sandstones 2000 ft. thick, which are probably Cretaceous in age¹³ and much resemble the Nubian Sandstone Series of Egypt. In their upper part they contain volcanic matter and are succeeded by rhyolitic ash-beds, breccias, and lavas, with a few doubtful andesites¹⁷. These are followed by basalts (with or without olivine) occurring in massive flows, many of these lavas being identical with those of the Deccan in India, and for this reason, and for their relation to the limestones and sandstones, they are held to be of Upper Cretaceous age⁶, and consequently to be older than any of the volcanic rocks of the coast.

The beds in Gebel Shiap dip on the whole¹ south-west at an angle of about 40°, but they seem to have been disturbed by gentle folding in some places, and to form low anticlines or domes. The mutual relations of the several formations are not clearly known. It is probable that in some cases the volcanic rocks are contemporaneous with the sedimentary deposits, as is known to be the case with the Upper Cretaceous of Baluchistan and Persia⁶. Some of the dykes and supposed necks may be of later date.

There exists a close relation^{18 17 17a} between the Mesozoic formations of southern Arabia, Somaliland, Abyssinia, and Eritrea, and we may add East Africa, and some of the marine Jurassic species are identical. A useful summary of the geological formations in southern Arabia in relation to that of other parts has been given by Lamare¹¹. The western part of the Protectorate is imperfectly

known geologically¹⁰, but the Upper Jurassic and Cretaceous rocks appear to extend into it.

In the eastern part^{12,17} of the Protectorate which extends all along the coast and includes the Hadramaut, Jurassic and Cretaceous limestones¹⁷ occur as in Oman, and Middle Eocene limestones near Shabwa and Makalla¹³ containing a few mollusca and other fossils are also known. There are also beds of salt and gypsum with oil-shales, lignite, and bituminous limestones, and these are referred to the Oligocene and Miocene. They attain a thickness of over 600 ft. and contain a few fossils. The gypsiferous beds near the top of the series resemble those of the Fars Series in Persia. A limestone conglomerate series¹³ occurring in the Makalla area up to heights of over 3000 ft. above sea-level seems to be of various ages ranging from late Miocene to Pleistocene or later. The Raised beaches in the Makalla¹³ district contain Pleistocene mollusca of which most occur in the raised beaches of the Red Sea.

General Relations of the Aden District.—The Gulf of Aden is regarded as a sunken portion of the plateau which includes southern Arabia and the eastern horn of Africa, to which the island of Socotra belongs. The lines of fracture along which this block has subsided run E.N.E.-W.S.W., and follow approximately the north and south coastlines of the Gulf, and meet at an angle the meridional faults of the Rift System of East Africa, which are probably much younger in age (see sections on Somaliland and on Rift Valleys, East Africa).

As is generally the case, the margins of the sunken region are marked by volcanic activity, and the volcanoes of Aden and of the neighbourhood of the Straits of Bab-el-Mandeb are in intimate connection with the structural characters. Though it is probable^{8,9} that they belong to the same period of vulcanicity as that which was associated in East Africa with the formation of the Rifts, the precise geological date of these eruptions on the coast has not been definitely determined, but it is probably Pliocene.

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PERIM ISLAND

General Characters.—Perim Island is situated at the narrow mouth of the Red Sea, and measures about 3 miles *in* length by 1½ miles *in* breadth. It has roughly a horseshoe shape, a harbour occupying the concavity on the south. The eastern and southern parts of the island are hilly, but low plains extend inwards from the coast, especially on the north side, and these seem to represent marine terraces or beaches raised less than 12 ft. above sea-level. The central depression of the Rift Valley of the Red Sea occupies the broader strait on the west side of the island, but the sea is elsewhere shallow around it. The Red Sea, which has the character of an enormous fiord, has a fairly flat floor which sinks by a slightly undulating slope to a depth of over 1000 fathoms near its middle, but rises towards its southern end so as to form the comparatively shallow threshold on which Perim Island is situated.

Geology.—The basement rocks of the island are volcanic and belong to part of the same series and period of eruption as those of Aden. Probably they were poured out from some crater to the

west of the latter place, and are in close relation with the tectonic history of this fractured and sunken area. They consist of nearly horizontal flows of basalt or andesitic-basalt, with volcanic tuffs containing felsitic nodules, while in one place a white pumiceous tuff is known to occur.

There is no sedimentary rock on the island except raised beaches containing Pleistocene mollusca³ and a Recent whitish coral sand or mud, enclosing ejected or weathered blocks of basaltic lava, and reaching a thickness of about 7 ft.

The scattered islands in the Red Sea are mostly of Recent volcanic origin and the craters are preserved in many cases². But the Farsan Islands, Gizan and Kamaran Islands⁴ (the last-mentioned of which is under British administration) consist of a series of limestones containing a somewhat mixed assemblage of Mio-Plio-Pleistocene and living molluscan species^{4a}.

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THE KURIA MURIA ISLANDS

These islands, five in number, with a total area of 28 sq. miles, lie a short distance off the lofty granite promontory of Ras Nus on the Arabian coast, and belong structurally to the Arabian plateau, the southern margin of which is apparently determined by parallel faults along the coast.

They are composed essentially of red and grey granite gneisses and schists pierced by dykes and veins of diorite and of a green diallage-rock (euphotide) or serpentine. The precise age of these igneous rocks which penetrate and (according to Carter¹) surmount the granite is not determined, but it may possibly be the same as that of the Uthologically similar rocks in the Oman Mountains which Pilgrim³ ascribes to a post-Triassic but pre-Cretaceous period. They may, however, be regarded as uncjoubtedly of the same age

as the *Semail Igneous Series*⁴ in Oman (q.v.) and as belonging to this series⁴.

Resting on these older igneous rocks are fossiliferous Cretaceous and Tertiary Limestones, which are stated to be considerably disturbed in places.

The succession seems to be similar to that on the adjacent mainland¹⁴, where the Cretaceous limestones are referred to the Cenomanian and contain a fauna², on the whole of a European type, though it also possesses several species which occur in the Bagh Beds of the Narbada Valley, India (see p. 446).

The Tertiary limestones are probably of Eocene age like those on the mainland, and appear to resemble closely those of Sind and eastern Baluchistan, but their precise correlation has not yet been determined.

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SECTION II.—OMAN (PROTECTED)

The territory of Oman³⁻⁵ under the Sultan of Muscat is geologically connected with the Persian Gulf on one side, and with that of the Kuria Muria Islands and southern Arabia on the other. Its orogeny⁴⁵ is connected with that of the Zagros Mountains on the north side of the Persian Gulf. Two principal periods of folding and faulting are apparent in the orogenetic zone, one Mid-Cretaceous and the other post-Miocene. The oldest rocks are crystalline (gneisses, schists, and quartzites) which only outcrop in small areas, as at Murbat on the coast and in the Kuria Muria Islands, and are pre-Permian. Some shales may be of Cambrian age. The earliest fossiliferous rocks are of Permian age and contain *Richthofenia*, *Productus*, *Lyltonia*, *Derbya*, *Streptorhynchus*, and other brachiopods^{2 3}. Such occur in Elphinstone inlet near Ras Musandam, and consist of blue and black massive limestone. Fossiliferous rocks of this age also occur just around Muscat. Triassic shales, sandstones, and limestones containing *Myophoria* are also present near Elphinstone Inlet, but the upper part of the *Musandam Limestone* of Ras Musandam is of Neocomian age, containing characteristic fossils.

There is also a series of shales, sandstones, red and green radiolarian cherts known as the *Hawasina Series*, the precise age of which is somewhat doubtful. Following them (but older than the Upper Cretaceous) is a great igneous series of rocks, known as the *Semail Igneous Series*, consisting of various lavas (quartz-keratophyres, to basalts, etc.) and intrusive rocks (serpentine, gabbros, and diorites) which are intensely folded and overthrust. These rocks extend S.S.W. to Masira Island and Ras Madraka on the coast, and occupy a great crescentic area behind the coastal plain on the south side of the Gulf of Oman, and probably are the same as those on the Kuria Muria Islands. Upper Cretaceous (Cenomanian and Campanian) fossiliferous beds succeed them after a Mid-Cretaceous orogenic disturbance and folding, and are transgressive. Middle Eocene beds with nummulites and echinoids, probably corresponding to the Mokattam stage of Egypt, succeed the Upper Cretaceous in the coastal area, and Miocene fossiliferous shales and limestones are found farther inland in Sur. Post-Miocene folding occurred, but no Pliocene beds seem to be present. Late Pliocene movements which followed the trend of the folds parallel to the Persian Gulf and Mekran coast indicate a still later period of disturbance. The orogenic zone of earlier movements is, however, nearly at right-angles to that of the Persian Gulf, for it passes through Oman in a

southward direction at first, bending a little to the west to run down the coast to Ras Madraka, where it seems to disappear under the Arabian Sea. Recent epeirogenic movements are evidenced by raised marine terraces of which one at 100-150 ft. is conspicuous, but others have been noticed up to over 1000 ft. The fiord-like inlets on the Ras Musandam promontory, with walls up to 3000 ft. high, suggest recent local subsidence and the drowning of valleys⁵.

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SECTION III.—THE BAHREIN ISLANDS

The Persian Gulf in which these islands lie may be regarded as a zone of sunken foreland, but they are not fragments of a plateau or of a block of ancient rocks, for they are composed of folded Cretaceous and early Tertiary strata which have been crumpled in late Tertiary times, and the movements which have thrown the beds into a series of parallel folds on the mainland along the north side of the Gulf are responsible for their origin.

The largest of these islands, 27 miles long, which gives its name to the group and is economically important because of the discovery of oil-bearing beds below the surface rocks, is encircled by a narrow coastal plain rising up to a flat plateau, which is widest at the north end and lies at a general elevation of 150-200 ft. above the sea. This plateau breaks off in an almost continuous line of cliffs, 80-100 ft. high, surrounding an inner sunken oval area about 12 miles long by 4 miles wide, which forms a plain at sea-level with a few hills rising above it, and culminating at its southern end in a group of peaks known as the Jebel Dukhan, rising to a height of 440 ft.

Geologically¹ the plateau and central area consist of a series of Tertiary limestones, marls, and shales, all characterised by the large amount of siliceous matter and much disseminated gypsum and salt. These beds are arched up into a long low dome, the axis of which coincides with the length of the island and has been denuded, the Jebel Dukhan consists of hard brown limestone with calcareous chert, and being in the core of the saddle exposes the lowest and oldest beds in the succession. The surrounding oval depression is composed of the overlying softer marls, sandy beds, and limestones, and these beds are permeated by salt and gypsum, and contain layers of flint and chert nodules with abundant large quartz geodes. In one place an asphalt-bearing rock occurs. The cliffs show sections of hard limestones with thin shales, and the upper beds, which contain flints in abundance, form the plateau. The fossils include *Nummulites beaumonti* and *N. lævigatus*, both of which occur in the Kirthar Group of India, as well as echinoids and mollusca. The majority of the species of mollusca found on Bahrein Island⁵ occur in the Middle Eocene of India, Somaliland, and Egypt, though a few of the species are also known in the European Eocene⁵. While only Eocene and Recent rocks are exposed on the surface, the parent oil-bearing rocks struck in bores are of Middle Cretaceous age, and consist of porous limestones and sandstones, overlain by cap-rocks of Upper Cretaceous and Eocene age.

A miliolitic formation similar to that in other parts of the Persian

Gulf, and chiefly composed of the tests of foraminifera, occurs in two places, and is considered to be of æolian origin and PJeistocene age. The sub-Recent deposits along the coast and in the interior depression are old beaches and sands containing Recent marine shells.

The anticline by which the Eocene rocks have been raised up belongs to the same system of folds as that developed on both sides of the Persian Gulf^{1-3 6}, and it has the same general trend as in Oman, running parallel to the coast-line. It was formed in late Pliocene times by the great movements which affected the whole area. To what extent longitudinal fault-lines are also concerned in their formation is unknown, but after the original subsidence of the tract on which the islands lie and a period of marine erosion, a certain amount of elevation has taken place. The island is remarkable for its abundant fresh-water artesian springs.

The smaller islands in the group are of Recent or coral formation.

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SECTION IV.—KOWEIT (PROTECTED)

No detailed geological survey has been published of this area, but it is believed that the borings which have yielded oil are in the Fars Series (Miocene), or in the Asmari Limestone (Oligocene), which are the productive horizons in south-west Persia^{1 2}, though it is possible that the mother rock is Cretaceous as on Bahrein.

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CHAPTER X I I

SOUTH-EAST ASIA

SECTION I.—THE STRAITS SETTLEMENTS AND PROTECTED MALAY STATES

General Characters and Structure^{29 37 50 52 53 57 61}.—Structurally, the Malay Peninsula, together with Lower Siam, belongs to the Archaean plateau which lies within and to the east of Suess' broken 'Sumatran marginal arc'¹⁶. This arc connects the fold-lines⁶⁰ trending southwards through the Arakan Yoma in Burma with those passing through the Andaman and Nicobar Islands, and thus into the East Indies^{29 37}. Farther to the east it was thought to be continued⁵⁷ through New Guinea, but, according to Molengraaff³¹ and Gregory³², it more probably ended in the Banda arc which is bent back to the north in an open curve like a fish-hook round the east side of the Banda Sea⁶⁰ where there is much complexity of the lines of folding, as recent bathymetrical investigations in the neighbouring seas have proved⁶⁵. But various interpretations of the course of these fold systems and of their interlocking and interference to the south and east of Borneo have been put forward^{50 52 57 58 60}. Scrivenor²⁹ describes the Malay Peninsula as belonging to a region of a strongly-marked series of arcs arranged *en echelon*, trending south-east to the island of Billiton, and then bending round to the north-east through Borneo and on to the Philippines. The foundered area of the Bay of Bengal lies outside and to the west of this arc, and there is also a sunken belt stretching inside the festoon of the Andamans and Nicobars, separating them from the Peninsula on the east.

Geologically^{1 8 23 37}, the Malay Peninsula consists of a main composite granitic axis traceable from Tavoy in the north down to Kedah, and south or south-eastwards into Negri Sembilan and thence to the coast of Malacca⁵⁶. The granite, which is late Mesozoic, as in the Butch islands, forms now a series of more or less parallel ridges occupying the cores of anticlines and complicated folds into which the older rocks have been thrown. In places there are traces of overthrusts from the W.S.W.²⁹. Associated with the granite are various metamorphic rocks.

On the west of the main axis there are hills in Perak and Selangor composed chiefly of quartzites with some conglomerates and shales, **and** these rocks form a large part of Selangor.

On **the** east of **the** main range in Pahang there is first a chain of

hills composed of the same series of quartzites, conglomerates, and shales, flanking the granite and running north into Kelantan and south into Negri Sembilan. Farther east is a huge isolated range of hills of granite and syenite forming the Benom Range in Pahang and probably extending south, sub-parallel to the main range. Still farther east there is a great belt of hilly country extending through Pahang and to the north and south of this State, and this tract is composed of quartzites, conglomerates, and shales. Farther to the east there are more granitic ranges.

Apart from these granitic and quartzitic ranges there are numerous isolated limestone hills^{19 28 34} in Kedah, Perak, and Pahang, which are conspicuous on account of their precipitous sides, and probably owe their shape and position to faulting which seems to have happened in connection with the intrusion of the granite masses²⁴. The origin of these isolated limestone hills has been a matter of discussion, and Cameron²⁸ would reject the theory of block-faulting and explain them as the result of unequal denudation of a strongly-jointed and comparatively gently flexured limestone lying on a floor of older heavily folded and sheared beds. It is possible, however, that they are residual fragments of a nappe of beds overthrust from the east and resting on a thrust-plane, as may be suggested by Cameron's view that the limestone of the hills rests unconformably on the rocks of the plain or valley. Rastall^{34 63} supports the view that overthrust together with block-faulting and erosion are sufficient to account for the origin of these peculiar isolated hills.

The western and eastern coasts of the Peninsula are mostly low-lying and sandy, and consist of Recent alluvium. No systematic and connected geological survey of the whole Peninsula has so far been made, but Scrivenor's^{29 37} work is the chief authority on the region.

The island of Singapore⁴⁵ has the western half occupied by Triassic and Jurassic¹⁰ sandstones and shales (see below), the middle and eastern half by granite and some associated gabbro. In a few places quartz-porphry and volcanic rocks²² (Pahang Volcanic Series) also occur (see below), and there is much alluvium.

STRATIGRAPHICAL SUCCESSION 1⁹

With the exception of some Tertiary fresh-water beds in Selangor no foossiliferous beds later than Upper Gondwana have been found in the Peninsula. The position and age of some of the older beds is uncertain. The following list of formations and their sequence is based on Scrivenor's work :—

5. Tertiary (fresh-water or terrestrial beds).		
4. Intrusive granites (Mesozoic).		
3. Tembeling (Gondwana) Series.	} Pahang Volcanic Series.	
2. Raub Series (including the Chert beds)		
1. Older granite (? not found in situ) ² .		

The **Older Granite** is only known from boulders found in the Gondwana Series and in the Pahang Volcanic Series.

The Raub Series^{18 40}.—This series comprises the oldest sedimentary rocks in the Peninsula, and is largely calcareous. It forms much of the low-lying ground, and is best seen in the Pahang River Valley. The limestones of which it is composed are mostly crystalline and white, grey, black, or reddish in colour. Some shales containing fine volcanic ash occur in the series. Carboniferous fossils¹ belonging to the cephalopod genera *Orthoceras*, *Cyrtoceras*, *Gyroceras*, and *Solenocheilus* have been identified from it^{18 36}, while from calcareous shales¹⁶ a small fauna of apparently Upper Productus Limestone age has been obtained. Crinoidal limestones also occur¹⁰. In Kuantan, Pahang, near the east coast of Malaya, Carboniferous corals in a limestone of Viséan age, probably on the horizon of the *Dibunophyllum* zone, have been collected. The best development of Carboniferous rocks is in the Langkawi Islands⁴⁶ off the coast of Perlis, where limestones to a considerable thickness, with quartzites and shales, are exposed in coast sections. From the extreme north of Perlis, on the Malayan-Siamese frontier, a few fossils have been collected in quartzites which, by the occurrence of *Fusulina*, etc., indicate that Ouralian-Permian rocks are developed there³³, and suggest that the rocks are an extension of the Burmese Anthracolithic System and correspond to the Fusulina Limestone of Sumatra⁵³.

The Raub Series is partly the continuation of the Carboniferous Limestone of Moulmein in Burma and of the Permo-Carboniferous of the islands of Sumatra, Timor, and Rotti. In addition to these marine fossils W. Edwards has described Carboniferous plant-remains (*Pecopteris* and *Cordaitea*) from Kelantan.

It is to the Raub Series that the limestone masses forming the precipitous hills in the Kinta Valley⁶³ and elsewhere must be ascribed^{19 24}, but no fossils of determinable genera or age have been found in them³⁶. The phyllites and altered calcareous rocks in Malacca⁶⁶ are believed to be also of Carboniferous age, but they may belong to the Tembeling Series (see below).

Associated with the Raub Series in Pahang, and partly interbedded and contemporaneous with it, but ranging up to later times, is a series of volcanic rocks known as the **Pahang Volcanic Series**^{1 13 16 18 43}. This is widespread in the interior of Pahang to the west of the main Raub outcrop, but to a greater or less extent it is also found in Singapore Island²², Johore⁴⁸, Negri Sembilan, Selangor, Perak, Kelantan, the islands off the east coast, and also in the more northern states. It is composed of lavas and ashes with hypabyssal rocks, and includes such rocks as rhyolites, trachytes, andesites, quartz-porphry, granophyre, porphyrite, dolerite, etc., but by far the greater part of the series consists of fragmental rocks. The rocks are frequently strongly sheared and metamorphosed, and become schistose near the junctions with the granites. Though the igneous activity lasted on into the period of the deposition of the Permo-Carboniferous and Triassic beds, yet it was at its maximum during the Raub period. The serpentine¹⁶, which frequently occurs at the junction of the Raub and Gondwana rocks is an altered lava, but its relations to the Pahang Volcanic Series are not precisely known. A similar igneous series is found in Sumatra and Borneo.

There is a series of radiolarian cherts⁸ and shales associated with the Raub Series (and perhaps forming only a higher phase of it) which is known as the **Chert Series**. The beds are best exposed in Pahang, Selangor, and Kedah, and occur on the Pahang River in association with lavas and ashes. The chert is sometimes green and sometimes bright red in colour, but the shales are light grey or yellow. The cherts contain radiolaria⁸⁶, and both cherts and shales

possess abundant carbon supposed to represent algal remains. But they are not deep-sea deposits, according to Scrivenor, and differ markedly from the radiolarian rocks of central Borneo. All the beds are much folded and are invaded and disturbed by granite⁵⁶ and other intrusions, and are pierced by auriferous quartz-veins.

The Chert Series was placed below the Raub Series by Scrivenor in 1907, but the precise age of all these radiolarian beds is somewhat uncertain, though similar beds in Borneo^{52 59}, and elsewhere in the East Indies⁵⁷, are referred to the Trias⁵⁹ or Jurassic. The bulk of them in Malaya come immediately above the Permo-Carboniferous. In Selangor and Negri Sembilan the cherts are found interbedded with quartzites and phyllites⁵⁴.

Tembeling Series (Gondwana Rocks).—This series, which is regarded by Scrivenor to be more or less equivalent to the Gondwana System, consists of quartzites, grits, shales, clay-slates, and conglomerates. It is unconformable to the Raub, and contains pebbles of radiolarian chert, but both are invaded by the granites and other Mesozoic intrusive rocks.

The phyllites and quartzites of the Kinta Valley⁶³, together with certain carbonaceous shales, as well as various schists, due to metamorphism of these beds by the intrusive granite, are referred to this 'Gondwana' Series. In Pahang they have been reported¹⁸ as succeeding the limestones, where a shale with Triassic fossils has been described⁴¹ by Cox. In Malacca⁵⁶ the Triassic sandstones, quartzites, and shales, which are invaded by the granite, have yielded no fossils.

The quartzites, phyllites, and shales have a wide extension in Perak and Selangor, but are mostly unfossiliferous, except in one case in North Perak, near Taiping, where a species of *Halobia*²⁵ (previously referred to *Estheriella*) has been found⁵. In Kedah^{26 36} also, members of the genus *Halobia* have been recorded, pointing to the wide extent of Triassic beds in Malaya. In the Trias of Kelantan⁵⁵ the tree *Dadoxylon* has been found.

The quartzites are largely weathered into sandstones, and in Pahang there is a sandstone which has yielded a Rhsetic fauna and is known as the **Myophoria Sandstone**^{9 18 27}. The fossils include *Myophoria ornata*, *M. mcequicos fata*, *Chlamys valoniemis*, *Gervillia inflata*, and *Pleurophorus dongatus*, the whole assemblage having a European facies, and unlike that of the Napeng beds in Burma. The characteristic Triassic fish *Semionotus* also has been found in them.

The peculiar 'Gopeng beds' of Kinta^{4 11 19}, which consist of clays, usually distinctly bedded and crowded with boulders of various rocks and sizes, and resting on an irregular worn limestone surface, were attributed to the Gondwana by Scrivenor, who compared them with the Talchir boulder-bed of India, but his interpretation of the facts and his conclusions no longer are held (see below)⁶. A large number of the boulders are composed of tourmaline-corundum rocks which are regarded as metamorphosed oolitic limestones and radiolarian cherts¹⁹. It is in these clays that the tin-ore chiefly occurs (see 'Economic Geology').

In the island of Singapore^{710 45} Newton²⁶ has described a marine Triassic fauna with a facies comparable to that of the St. Cassian beds of Europe, and it is probable that the beds containing it are an extension of the Myophoria Sandstone of Pahang²⁷ and of the Amherst Triassic beds⁵¹. There are also fossiliferous clays, violet, purple, chocolate, drab, or yellow in colour, associated with conglomerates, sandstones, and shales, regarded as of Middle Jurassic age^{710 36}, and as being about the horizon of the Inferior Oolite. This series of beds is disturbed and highly inclined or vertical. The fossils include species of *Cuctidacea*, *Gervillia*, *Volsella*, *Astarte*, and *Goniomya*, together with

some remains of plants, *Podozamites* cf. *lanceolatus* and *GarpolUhes*. On the strength of the plants Newton suggests a connection between them and the Upper Gondwana beds of India.

Intrusive Granites, etc. It was previously held^{1 2 13} that all the granite ranges in the Peninsula were approximately contemporaneous and of Mesozoic or earlier age. But this view is no longer maintained, for the only evidence of older granites consists of pebbles in the Pahang Volcanic Series, and it is now held that the intrusions took place chiefly in late Cretaceous or even Tertiary times^{113 56}.

The granites are mostly porphyritic¹⁸, and occasionally contain tourmaline, but there is also a non-porphyritic variety. In the Benom Range there are many types of granite and also syenites, but most of the range is composed of hornblende-granite. The igneous rocks of this Benom anticline coincide with the gold-belt of the Peninsula. The Kuala Selangor granite contains tourmaline and cordierite.

The island of Penang is stated to consist entirely of granite.

On the island of Singapore^{22 45} hornblende-granite, biotite-granite, and quartz-diorite occupy most of the centre and northern coast, and form the small adjacent island of Pulau Ubin, where the normal type of granite is predominant; quartz-monzonite is also found. The granites metamorphose the dacites and dacite tuffs of the Pahang Volcanic Series near Singapore, and cause alteration in the Raub and Tembeling beds wherever they come in contact with them, so that their intrusion must be post-Triassic.

The gneissic types of granite in the Peninsula have probably been produced by movements in the partially solidified magma. The granite of the Main Range is highly weathered, and consists at the surface of red or yellow clay, with rounded core-boulders ('wool-sacks') embedded in it, while kaolin has been formed on a large scale, and occurs as veins in the limestones or clays.

The newer granite is stanniferous⁶ in many parts like the 'older' granite boulders in the Gopeng beds⁴, and the sedimentary rocks in contact with the granites likewise frequently carry tin.

Later igneous rocks, probably of Tertiary age, pierce the granites, and amongst them are the dolerite dykes on the Peninsula (e.g. in Pahang) and the enstatite-vogesite and amphibole-vogesite in Singapore. Veins of quartz-topaz rock and topaz-aplite traverse the porphyritic granite on the borders of Selangor and Pahang²⁴.

Tertiary.—In Selangor^{124 49 62} a small area occurs where coals (of poor quality), clays, sands, and shales rest unconformably on the much-disturbed Tembeling quartzites and clay-slates, and they are not altered by the intrusive granite. One seam of coal has been proved to be 40 ft. thick, and the shales yield fossil leaves resembling existing jungle types; some crushed shells (*Helix* ?) also are found in them. The shales at the top of the series contain traces of oil. Probably the site of the whole series of deposits was a lake of much greater extent than indicated by the small patch of beds preserved. In Johore⁴⁴ a fossiliferous fresh-water shale containing species of *Viviparus* is probably of Miocene age.

Pleistocene and Recent.—In Perlis²⁴, north of Kedah, the existence of a limestone cave containing the remains of Recent marine organisms, and situated at an elevation of 300 ft. eleven miles inland, is believed to indicate a Recent partial submergence of the whole Malay Peninsula, and its temporary separation from the mainland. The zoological evidence adduced by Wallace seems to be in accordance with this conclusion. It is held by some geologists⁶⁴ that the Pleistocene glaciation had a great influence on the variation of the

sea-level in these parts, and that its lowering was sufficient to unite Sumatra, Java, and Borneo to the mainland.

The alluvial deposits which cover the coastal plains and occupy the depressions and valleys are generally of the nature of a dark blue clay, but their composition and character vary, and in the Kinta Valley include beds of lignite and peat. The coal-veins filling fissures in older rocks are probably of late formation⁴⁹. Most of the deposits, however, are composed of the debris of the granitic rocks. It is in these deposits that the tin is chiefly found. The tin-bearing stratum is associated with irregularly stratified layers of sand and clay, and generally occurs near the base, averaging 5 ft. in thickness. The stanniferous clays of Kinta, which Scrivenor^{4 17} at first claimed to be of glacial origin and of Gondwana age, are now regarded by most geologists as merely residual products, and to have been derived from the decomposition of the schists, phyllites, and intrusive granites resulting from the prolonged weathering of the rocks *in situ*^{6 14}. Many of the tin-bearing deposits are undoubtedly only rock deeply weathered *in situ*, and not transported material, but others are of torrential or alluvial origin¹. As above stated, the peculiar *Gopeng Boulder-beds* are now regarded as alluvial deposits of sands, clays, and boulders, the boulders having sunk into the soft clays after their deposition. They must be regarded as of Pleistocene or Recent formation, and of torrential origin and not glacial deposits. The distribution of the coral reefs in the neighbouring seas was influenced by the Pleistocene glacial period⁶⁴.

Tectonics.—It was in post-Gondwana times, probably in connection with the intrusion of the granites²³, that the chief upheaval and faulting of the older rocks occurred²⁹. The main faults trend N.N.W. to S.S.E., but there is another set of dislocations transverse to them. The formation of these fractures was probably concerned with the break-up of Gondwanaland, but some may be of much later date. The chief orogenic period^{37 39 60} was in the Cretaceous, but important folding of the beds took place during Miocene and Pliocene times, as in the case of the Himalayan zone⁵⁰.

ECONOMIC MINERALS^{35 4048 54 62}

Tine 14 18-20 35 37 38 40 42 47 48 63 perak is the lar of tin, but the mineral occurs in all the States. The greater part of the tin comes from the so-called alluvial deposits, which are of many types. Some are detrital, such as the granite boulder-beds, others are residual, being due to the weathering of the rock *in situ*, often to a great depth; and some as gravel, sand, or silt occur in limestone caves and fissures into which these materials have been washed. The tin may occur scattered indifferently through the alluvium or be concentrated in layers. The tin-bearing layer, which is known as 'karong,' occurs from near the surface down to considerable depths in the alluvial deposits. The ordinary tin-bearing strata vary from 1 to 30 ft. in thickness, but sometimes are much thicker.

The tin-ore (cassiterite) is derived from the older rocks, where it

occurs in veins, pockets, pipes, and impregnations, chiefly in the granite, but fissure-veins also occur in slates and schists, as in Pahang, and the veins of a quartz-topaz rock and of pegmatite which traverse the granite are also found to carry tin. In the Raub Limestone there are occasionally lodes, veins, or pipes, as at Lahat²⁰, where the tin ore is accompanied by a large proportion of metallic sulphides. In the Raub district Richardson⁴⁰ recognises eight stages in the mineralisation; the tin is the earliest and occurs as veins in the granite; the gold, which also occurs here, marks a later stage and is found in the Permo-Carboniferous shales.

It appears probable that the tin ore is of two generations, and occurs in the older as well as in the newer granites⁵⁹.

Tungsten^{21 35 54 62}.—Associated with the detrital tin-ore are various heavy minerals known collectively as 'amang' and containing tungsten in the form of wolfram or scheelite⁵⁴. Wolfram also occurs in quartz-veins together with the tin-ore, and where the veins traverse the schist they are much richer in wolfram than where they traverse the granite. The scheelite⁵⁴ occurrences are in limestone near its contact with the intrusive granite. In Trengganu rich veins of wolfram have been found traversing much disturbed quartzites, schists, and slates. The whole system of wolfram-veins and deposits is a continuation southwards of that developed in Tavoy (see India and Burma), where the ore occurs under similar conditions.

Iron.—In Johore⁴⁸ there are important deposits of iron-ore (haematite and magnetite) associated with the Pahang volcanic rocks.

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SECTION II.—BRITISH BORNEO

General Characters and Relations.—The British portions of the island of Borneo consist of British North Borneo, comprising the northern part of the island, the island of Labuan, the province of Sarawak, and the small state of Brunei, in all embracing an area of about 84,000 sq. miles. Geologically they are little known, and the observations which have been made are mostly disconnected and uncorrected¹⁷.

The mountain chains are intimately connected with the structure of the neighbouring island groups³⁵, as Suess³ and Brouwer²² have pointed out. The inner arc of the Philippines is prolonged southwards through Borneo, running in a gently curved manner nearly parallel to the west coast from the northernmost point of the island. From lat. 1° 30' the direction bends gradually to the west and then to the north-west, and finally reaches the western coast of Borneo in Cape Datoc and the Gading Promontory. This arc practically separates Dutch from British Borneo south of the northern province, and it is composed of ancient crystalline, metamorphic, or igneous rocks. No complete geological survey¹ has yet been made of any part of the British territory, so that the isolated observations leave many points unsolved, though our fuller knowledge of the adjoining Dutch area^{21 22} is of considerable help in interpreting the British provinces.

The relations of the East Indian islands^{21 22 25 28 30} 35 including Borneo, to the mainlands of Asia and Australia and to New Guinea are very complex and have been variously interpreted. The distribution of the so-called 'ares' and 'troughs' as well as their relative ages have resulted from folding movements, elevation, or subsidence of the crust at more than one period. It may be observed that the troughs and basins are often of irregular shape but that the convexity of the arcs is generally eastwards.

DETAILS OF THE FORMATIONS

Archæan or Pre-Cambrian (?)¹⁷¹⁹.—The ancient rocks¹² forming the core of the above-mentioned arc and axial mountain chain may be provisionally referred to the Archæan or Pre-Cambrian, but their precise age is undetermined, and some of the rocks may be altered sedimentaries of a much later date. They comprise strongly folded amphibolites and chloritic schists, with various gneisses, granites, and gabbros. These igneous rocks probably belong to more than one period. At the north end is the elongated *massif* of Mount Kinibalu in Keppel Province, 20 miles from Ambok Bay; it rises to a height of nearly 13,700 ft., and is composed of syenitic granite. Schists of various types have been observed along the ridge, but on the upper course of the

Sikajam, where the chain turns to the north-west, bosses of gabbro replace the schists. At Cape Dato schistose rocks are again exposed, and granite forms the Gading Promontory. In the neighbourhood of Darvel Bay¹⁷, on the east coast of British North Borneo, the old rocks of probably Archæan or Pre-Cambrian age (at any rate in part) comprise crystalline schists, hornblende-gneiss, amphibolite- and mica-schists, granite, quartz-diorite, pegmatite, etc.

Palæozoic (?).—Flanking this granitic and crystalline axis are phyllites and clay-slates with a silky lustre, alternating with beds of sandstone, greywacke, and quartzite. The Upper Kapoewas chain, which runs almost east and west between Western Borneo and Sarawak, consists of these rocks. In Sarawak there is also much limestone, and Posewitz apparently refers these rocks to the Carboniferous, marking them thus in his map as a broad belt extending from the northern end of the island to the south end of Sarawak, so that he regards a large proportion of the stratified rocks of Sarawak, including the ore-bearing limestone hills, as belonging to this period. Tenison Woods⁴ stated that Carboniferous Limestone containing *Stenopora* and *Fenestella* occurred in one place, and he also recognised plant-remains of Lower Gondwana age (*Phyllothea australis* and *Vertebraria*) in some of the coal-seams in Sarawak. But the identification of these fossils is very questionable²⁴, and the coal-bearing beds in Borneo are undoubtedly for the most part of Tertiary age, the presence of true Gondwana beds not being satisfactorily proved. Auriferous quartz-veins occur in these Palæozoic (?) rocks in Sarawak and Western Borneo.

Mesozoic.—Between these older rocks and the coast there are Mesozoic beds which, in a few places, yield fossils, proving their age beyond doubt. Thus, at the western end of the Sarawak Province *Ostrea* (*Alectryonia*) *amor* D'Orb. has been found⁷ in a compact limestone containing also *Heteropora*, *Stylina*, and probably *Corynella*; these fossils point to a Middle Oolite age, while in the Dutch territory of Western Borneo immediately to the south of Sarawak a rich Liassic as well as Oolitic marine fauna has been found^{14 28}. The limestone in the Sarawak district from which the *Ostrea* (*Alectryonia*) *amor* is supposed to have come is stated to be full of fossils^{5 6}, and to contain the lodes of antimony which are of considerable economic importance. The limestone beds seem to be tilted almost vertically, and on their denuded edges rests unconformably a thick series of sandstones, conglomerates, and clay-shales of unknown age. Piercing the limestones and sandstones are intrusions of granite, basalt, porphyrite, and 'greenstones,' the latter being especially abundant in the antimony districts. It is probable that some, if not all, of the so-called 'Carboniferous Limestone' of Posewitz and Tenison Woods is of Mesozoic age; in Sarawak it has been proved to be of Jurassic age by the discovery of ammonites of the genus *Perisphinctes*²⁰ in an argillaceous limestone. The great limestone cliffs of Mount Mulu in Sarawak (long. 115°, lat. 4°) are probably also Jurassic.

Radiolarian beds like those in Dutch Borneo² have been described from Sarawak²⁰, and in the hinterland of Darvel and Sandakan Bays¹⁷, in North Borneo, hornstones, cherty shales of reddish or yellow colour, which contain radiolaria, are widely spread, and in the mountains in this eastern area are associated with diabases and serpentines¹⁹. The similar radiolarian²⁹ rocks in Dutch Borneo form part of the highly metamorphosed and intensely folded *Danau Formation*^{2 27}, and probably the radiolarian rocks in Java, Sumatra, and Celebes, and the Chert Formation of Malaya²⁴ are of the same age. Immediately south of the Kapuas Range on the south side of Sarawak there is a similar series of cherts, jaspers, quartzites, diabases, and diabase-tuffs

containing radiolaria, which is faulted down against Palaeozoic slates. They are regarded as probably of Triassic age. The folding of the Danau Formation took place before the intrusion of the granite batholiths which are present in many parts of Borneo, and are at any rate post-Triassic²⁵ in date.

Cretaceous rocks have not yet been recognised in situ in British North Borneo, but in the neighbourhood of the Seberuang River, a tributary of the Kapuas, close to the south-east corner of Sarawak, as well as in some other parts, pebbles or boulders containing fossils of Cenomanian and Senonian age have been found, and *Orbitolina-boaxing* rocks are known to extend over a large area in Western Borneo and in Sarawak, resting unconformably on the intensely-folded Danau Formation²⁵. In adjacent Dutch territory marine and lagoon-formed fossiliferous beds of Cretaceous age are known¹⁴, and in the Martapura district of Dutch Borneo in the south-eastern part of the island there is a series of marls, clays, and conglomerates which have yielded a rich Cretaceous fauna of the Ariyalur type of southern India, which is of much interest and importance from a zoo-geographical point of view.

From the general distribution and characters of the deposits around the Indian Ocean it appears that during Jurassic and probably Triassic times¹⁴ the sea extended westwards to east Africa, including Madagascar, and eastwards across the Pacific to America, and that Gondwanaland was already broken up in the western part of the Indian Ocean. In Cretaceous times this Pacific zoo-geographical province was no longer in direct communication with the Mediterranean as it was during the Jurassic.

Tertiary.—The Tertiary beds occupy a wide area in north-eastern British Borneo, and form a belt along the western coast 70-100 miles wide in an irregular manner extending down to the town of Sarawak. They consist of sandstones, shales, marls, conglomerates, and limestones with occasionally interbedded coal-seams or lignites, and are frequently petroliferous¹⁸. In the districts of Bau and Bidi the limestones which carry gold in irregular masses of chert accompanied by stibnite are overlain by marls containing fossils (undetermined); then follow shales, sandstones, grits, and conglomerates, and it is associated with these beds that the coal-seams of supposed Eocene age occur. These shales are in places auriferous¹⁸. The beds are affected by the system of folds which have a general south-west and north-east direction, and the oil-springs and mud-volcanoes are situated along the axes of these folds. Igneous rocks, especially dykes of quartz-porphyry, have also pierced and disturbed the rocks, as in Bau and Bidi, subsequent to the folding. In the series of Tertiary beds in the neighbourhood of Darvel Bay¹⁷ there are some of definitely Eocene²⁶ age containing *Nummmdites*¹⁴ and other foraminifera, and these beds which rest directly on the ancient crystalline rocks have been affected by folding before the deposition of the later Tertiaries. Eocene beds containing *Nummtdites javanm* and other foraminifera have also been found on the borders of Brunei and Sarawak^{8 81}, but the molluscan fauna of Eocene²⁸ age present in the beds of Dutch Borneo has not yet been described from British territory.

In addition to these marine beds there are the Brunei and Labuan coal-bearing series¹¹, which are referred to the Eocene, and it is probable that the so-called 'Gondwana' coal-beds of Tenison Woods⁴ in Sarawak belong to the same series. In Brunei the coal-seams, which occur in several places, seem to be of the nature of lignites. In the island of Labuan^{110 18} the beds, which are somewhat folded, consist of alternating beds of clay, sandstone, and conglomerate, containing several good coal-seams, and a sandstone has here yielded marine fossils (*Gerithium*, *Pynda*, *Fusus*, *Oliva*, etc.), and a slightly different assemblage of fossils occurs in a blue shale. The plant-remains

indicate a tropical flora; *Dipterocarpeae* are characteristic, and the tree-trunks are often of large size. At several places in Sarawak²⁰ good coals are known, and in British North Borneo on the river entering Cowie Harbour in Elphinstone Province there is the important Silompopon coalfield containing large quantities of bituminous coal¹¹. The beds here¹⁶ consist of sandstones, shales, and coal-seams, dipping generally gently to the south, but north of the Silompopon River the beds are more disturbed.

It is uncertain if all of these coal-seams belong to the Eocene, or if some at any rate are referable to later Tertiary epochs, their correlation being uncertain, for the succession has not been worked out in the British districts with the same precision as it has been in Dutch Borneo²⁶, where Miocene coals are known. It is believed¹⁶ that in early Eocene times a great continent on which these fresh-water and terrestrial deposits (including the coal-seams) were formed stretched from Sumatra to New Zealand, and probably included part of Australia.

Around Cowie Harbour^{27 31}, where the Tertiaries are represented by sandstones and shales, Upper Oligocene and Lower Miocene foraminifera have been discovered in the shales.

It is of importance to note that a **Miocene** series of limestones is present in parts of British Borneo, e.g. on the Malinam River and on Gomanton Hill in the Kinabatang district in the north-east part of the island. These marine calcareous deposits have yielded the typical fossil *Orbitoides* (*Lepidocyclina*) *mmatrensis*^{8 9} as well as other fossils, including corals, echinoids, and mollusca¹⁷. Martin has proved that in the Miocene and younger Tertiaries of the East Indies no European species occur. These Miocene beds are developed also in the Darvel Bay region, and have been affected, together with the older Tertiaries, by a post-Miocene period of folding¹⁷ which varied in intensity in different parts of the East Indies. Probably this took place at the end of the Pliocene or in the early Pleistocene after the denudation of the folded Miocene deposits. The more recent movements seem to have been of the nature of faulting and subsidence of vast areas in the marginal regions of eastern Asia, especially in the complex folded area of the East Indies^{25 28}.

Late Tertiary volcanic action is very evident in the north-west of Borneo; hills of basalt and felspathic porphyry have been described, and the Tertiary beds in the lowlands are pierced with dykes of various igneous rocks. On the north of Cowie Harbour²⁷ volcanic rocks (pyroxene-andesites) form hills and mountains, of which Tanjong Batu is a conspicuous example with a conical shape. This volcanic region extends to Darvel Bay^{16 17 85}. Some of the igneous rocks in the Sarawak area, which include quartz-porphyry, hornblende-andesite, etc., are also of Tertiary age, for they pierce the Tertiary coal measures. The quartz-diorite and hypersthene gabbro at Matang, Sarawak, are of uncertain age. In central Borneo Molengraaf mentions ranges of volcanic hills and plateaux composed of andesites and rhyolites ranging in age from late Cretaceous to the beginning of the Quaternary period. The peculiar 'obsidianite' (tektite) of supposed cosmic origin has been found in the gravels of British Borneo¹².

Post-Tertiary Deposits¹⁷.—Alluvial deposits are widely developed, and consist of sandy or pure clays with underlying conglomerates composed of pebbles of quartz, eruptive rocks, and Tertiary beds. They contain gold, platinum, and diamonds. The auriferous drifts^{8 2} are best known in Sarawak. Occasionally the beds are hardened by a siliceous cement, and beds of lignite are sometimes intercalated. These drift-deposits cover the lowlands and undulating **plains**, forming a belt of varying width extending from the northern parts of

the western coast down to Sarawak, and they also occur at various localities inland.

Recent elevation to the extent of several hundred feet is evidenced by the raised coral-reefs on many of the East-Indian islands^{26 84}.

ECONOMIC MINERALS

Gold occurs in the post-Tertiary alluvial deposits³², but it is found also in brecciated beds in Upper Sarawak, and in Bau and Bidi in limestones or as impregnations in shales¹³. The gold occurs in irregular masses in cavities and fissures in the limestones¹³. These sedimentary rocks, which may be of Jurassic age, are invaded by dykes and sills of igneous rocks which are mostly quartz-porphyrries. **Cinnabar** is found in a black shale and sandstone fault-breccia at Tegora. The occurrences of **Antimony**³² in the limestones have been mentioned above. There are also enormous deposits of **Manganese** at Tanjong Batu in the north of the island.

The **Coal**³² and **Petroleum**¹⁸ in the Tertiary beds have been above referred to, the petroleum apparently occurring in the same strata throughout the East Indies. The beds yielding it are for the most part considerably folded, and the oil-seepages occur along the anticlinal axes. In the British possessions one of the oil-districts is on the east coast close to the boundary of Dutch Borneo in the neighbourhood of Cowie Bay²⁷. Another is in Brunei Bay and on Labuan Island, and a third farther south on the west coast at Miri Bay¹⁸. The latter area yields oil from a sandstone formation of Miocene age.

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SECTION III.—ISLANDS IN THE INDIAN OCEAN

Mauritius.—The island of Mauritius^{117 18 36 41} is the central one of a group of three volcanic islands, known as the Mascarenes, of which the other two are Bourbon (French) and Rodriguez^{2 19}. On Bourbon eruptions still occur, but in Mauritius and Rodriguez volcanic action is extinct. Reunion, Mauritius, the Carcados Reef, Nazareth Bank, the Say a de Malha Banks, the Seychelles, and Amirante Islands all lie on the same submarine ridge curving from south-east to north-west surrounded by the 2000-fathom line^{38 40 41}. The coral reefs around them have been described by Gardiner⁴¹.

A central curved ridge runs across the island of Mauritius, bearing all the more recent craters, and the chief lakes lie also in craters. The whole island is practically composed of volcanic materials, and the mountains consist of superimposed lava-flows, but in two places much older rocks occur :—(1) in the south-west part a mass of coarse clay-slate stands up as a little hill in the Black River Mountains, and is surrounded on all sides by volcanic rocks ; (2) in the centre of the island the mountain called La Selle, which rises with bare precipitous cliffs on three sides in the midst of the forest, is composed of much contorted phonolite and trachyte, according to Shand³³. The greater part of the surface of the island is covered by a volcanic breccia, and by red earth formed by the sub-aerial decay of the underlying rocks.

The volcanic rocks in Mauritius have been stated to belong to two periods and all to be of a basic nature, but Shand denies this ; (1) the earlier are the so-called diorites, which are well developed in the Black River district, and apparently form most of the mountains, and (2) the later are the basalts or dolerites, frequently containing porphyritic feldspars, which were mainly poured out from the craters on the central ridge, and form terraced plains of lava in the centre of the island. Charred vegetable remains are sometimes recognisable in them. Drasche¹⁸ stated that the lavas are dolerites (basalts) rich in olivine, but Shand³³ says that some are quite free from it ; Drasche states that in places the flows alternate with coral reefs. A different type of rock (? augite-andesite) occurs in the Piton de Milieu. It is probable that the phonolite and trachyte of La Selle are the latest eruptives, and that this mountain is the central plug of a volcano, as on the island of St. Helena.

Raised coral reefs, 40 ft. above sea-level in the south and only 12 ft. in the north, suggest unequal elevation at a recent date. A large submarine platform extends from the north end of the island bearing several small islands. Several islets² off the coast are

said to have the limestone covered with a coarse sandstone, probably of ælian origin, showing curious cylindrical holes 1-2 ft. in diameter, like the West Indian 'palmetto stumps.' Caves and underground rivers in the lava flows are common. The island was the home of the extinct dodo.

Rodriguez^{2 19 27}, which measures about 18 miles in length and 7 miles in width, is 300 miles east of Mauritius, and is likewise chiefly composed of volcanic rocks, but from their much-weathered state and the extensive denudation which they have suffered all volcanic activity must have been long extinct. The island lies at the southern end of the submarine (Carlsberg) ridge⁴⁰, which consists of basalt and runs in a curved line southwards from Socotra, joining the much wider mid-Indian Ocean ridge⁴⁰ which extends to the Antarctic Continent. A lofty central range in the island rising to heights of 1100-1300 ft. extends from east to west composed of lava-flows and other volcanic rocks, and on the south-west it slopes down gradually into a broad limestone plain with occasional hills up to 500 ft. in height. The prevalent igneous rock is a coarse olivine-dolerite, but there are also basalts, some vesicular and some variolitic. The lavas are frequently columnar in structure, and have been poured out from a number of volcanic vents at successive periods. Beds of scoriæ and agglomerates are occasionally associated with the lavas, and between the flows there are frequently interbedded layers of red clay or ochre indicating long periods of quiescence between the eruptions during which extensive weathering of the lava streams took place. The coral-limestones which form the plain in the south-west of the island are later than the igneous rocks, and contain numerous caves which have yielded the remains of the extinct bird, the Solitaire (*Pezophaps solitaria*). Some limestone patches found in the volcanic region at a height of about 500 ft. indicate recent elevation.

The Seychelles

These islands^{3-5 13 20 38} are situated 940 miles north of Mauritius between the parallels of 4° and 5° south latitude, and lie upon a submarine bank about 30 fathoms below the surface of the sea. This bank extends in a general east and west direction, measuring about 190 miles long by 100 miles wide, and is surrounded by water about 2000 fathoms deep. The islands, of which the principal one is Mahé with a length of about 17 miles and a width of about 4 miles, are 34 in number and mountainous; they consist chiefly of granite belonging to a hornblende or hornblende-biotite variety mostly grey or red in colour. In Silhouette and Long Islands it is replaced by a typical syenite. In numerous places these rocks are pierced by

dykes or overlain by sheets of younger igneous rocks dark in colour and including hornblende-vogesite, olivine-diabase, diorite, dolerite, porphyrite, etc.; others are of an acid composition, such as felsite-porphyr, granite-porphyr, and syenite-porphyr. All the rocks are much weathered, and the steep bare faces of granite show remarkable parallel vertical rills or branching grooves due to weathering. Deposits of laterite are often several yards thick on the surface.

The presence of ancient sedimentary rocks is proved by the occurrence on Silhouette Island of clay-slates altered by contact metamorphism into andalusite-hornstone, and of an adinole-like hornstone on Stag's Island.

It is probable³⁸ that the Seychelles are a detached and only partially submerged portion of the ancient Gondwanaland, the other fragments of which are supposed to be scattered over the Arabian and Indian Seas and to be represented by the submarine ridges and banks now existing there as well as by various islands mentioned below.

A recent elevation of over 200 ft.¹³ is suggested by the existence of certain inland cliffs.

Small Island Groups to the North of Madagascar

North of Madagascar and south of the Seychelles are several small island-groups, such as the **Cosmoledo Group**²⁰, the **Aldabra**^{39 41} **Islands**, and **Farquhar Group**. All are of coral formation, but the basement is unknown. Probably it is formed by that part of the sunken mass of Gondwanaland, of which the Seychelles alone remain above water.

The islands of Aldabra, Cosmoledo, Farquhar, and Astove are atolls¹³, and all the islands seem to rise from a bank 1000 fathoms deep.

Aldabra^{15 26}, according to Voeltzkow, is formed of foraminiferal rocks elevated 20-80 ft. above sea-level, but according to Fryer²⁶ the whole of the atoll is formed of coral or secondary derivations from coral reefs. There are three types of rock constituting the land-rim; the first is composed of corals in the position in which they grew, and forms a zone completely round the atoll. The second type is of broken corals, shells, *Lithothliamna*, etc.; the third, which forms most of the inner part of the land-rim, consists of 'highly metamorphosed' coral rock with inclusions of calcium phosphate derived from former deposits of guano. Most of the small islands in the lagoon are composed of this third type of rock. The Aldabra atoll is of an elongated shape and 19 miles in length, and the lagoon is practically surrounded by land except in three places. The sea cliffs are often undercut, suggesting recent elevation.

On the Cosmoledo **Islands** masses of lava are described as visible on the shore, and probably form the foundation on which **the** reef is built up¹⁵. According to Fryer, Cosmoledo is a typical elevated atoll, the rocks having the same composition as those forming the land-rim of Aldabra, but the land-rim is very imperfect, and the proportion of metamorphosed coral rock is larger.

Farquhar Island²⁶ appears to represent a later stage in the life-history of an atoll than Aldabra or Cosmoledo. It is composed of accumulated sand resting on an elevated reef.

Providence Island lies to the north of Madagascar, and is stated by Gardiner^{38 41} to be an elongated surface reef built on basalt and volcanic ash and on an agglomerate of Eocene-Oligocene age, according to Wiseman³⁴,

The Amirante Islands

These islands, which lie about 120 miles to the south-west of the Seychelles and lead up to them, are situated on the submarine bank, stretching from the north end of Madagascar. Their exposed parts consist of the debris of corals and shells¹³, and rise only 10-20 ft. above the water, though it is probable that they have a foundation of crystalline rocks like the Seychelles³⁸.

The Chagos Archipelago

This group of islands^{37 41} in the Indian Ocean, 240 miles south of the Maldives, lies on a bank at a depth of about 700 fathoms, and is surrounded by water over 2000 fathoms deep. It is entirely composed of great atolls or lagoon-formed reefs surmounted by islets, as Darwin³ and Gardiner¹³ have described. Some of the islands are ordinary atolls, others are annular reefs, and others are more or less submerged banks. Of the last the Great Chagos Bank is the largest, measuring 90 nautical miles in length and 70 miles in width. The central part consists of a level muddy flat, 40-50 fathoms deep, and is surrounded by a steep bank or banks rising in steps and lying on an average about 16 fathoms below the surface; the banks, which are breached in places, measure from 5-12 miles wide. The outermost rim, which rises *in* some places into islets, consists of smooth hard coral rock with scarcely any live coral. There is evidence of a rise of the land from 5 to 35 ft. judging from the elevation of the dead coral reefs.

The Maldivé Group

This group^{14 21 22 28 35 40 41} also consists of coral islands of an atoll-like character, and measures about 470 miles in length, **with** an average breadth of about 50 miles. The islands **are** roughly

arranged in two lines running north and south and uniting at each end. The smaller islands have ordinary atoll characters, but the larger ones are breached by numerous deep-water channels leading into the central lagoon, and the separated portions are themselves frequently annular, all stages between linear banks and ring-shaped reefs being traceable^{3 14}. The nature of the common plateau on which the reefs are built is unknown, but it is probable that it consists of a sunken fragment of the old Gondwana continent. The islands themselves consist either of coral rock or sand^{38 41}. The rock is formed of corals, nullipores (possibly *Polytremas*), and detrital material; coral predominates, though sand fills the crevices and hollows. The Maldiv¹⁴ atolls belong to the class of atolls which rise from relatively shoal-water platforms³⁷, and never had any central land-area. According to Vaughan this type has been formed during or following submergence, and have been shaped by the prevalent currents. Intermittent movements of uplift are indicated by raised beaches and coral-reefs³⁵ in the group.

The Laccadive Islands

These islands^{14 21 35} which lie to the north of the Maldives off the Malabar coast, and at the head of the long submarine spur³⁸ extending from Bombay southwards to include the Maldives at its south end, are likewise of coral formation and consist mostly of circular reefs. It has been suggested that the line of upwarp which formed the Aravalli Range in India is continued south, and forms the basement of the ridge on which these atolls have been built up. The basement is unknown, but probably is a continuation of the sunken mass on which the Maldives rest, forming a submerged platform.

The Andaman Islands

The Andaman Islands^{6 23 32 35} stretch in a nearly north and south direction, and form part of the southern continuation of the arc of folded rocks (Theobald's 'Axial Group') which breaks off on the mainland at Cape Negrais in Burma after entering into the composition of the Arakan Yoma. This arc is prolonged still farther south by the Nicobar Islands and by the small islands off the west coast of Sumatra^{7 28}; the whole structure of these islands and the characters of their rocks link these land-areas closely together.

The Great Andaman is composed of three islands, North, Middle, and South, forming a low range of hills which rise to a height of 2400 ft. above sea-level, the higher hills and steeper slopes being on the east side. The coast-line is much indented, and numerous

archipelagoes of smaller islands lie off these larger ones. The Middle Andaman Island has been most closely investigated geologically³².

The oldest rocks are known as the *Serpentine Series*, and are pre-Tertiary in age, consisting of red and yellow jaspers, quartzites and pink and white porcellanic limestones. No fossils have been found in them, but serpentines occur in association with them, and from the general lithological similarity of the rocks to those of Cretaceous age in the Arakan Yoma and Baluchistan, their association with serpentine intrusions, and the occurrence of fragments of them in the Eocene conglomerates, it is believed that they are of Cretaceous age. There is no evidence that the serpentines are intrusive into any of the Tertiary beds. In addition to the serpentines, other altered basic and ultrabasic rocks, as well as dolerite dykes occur.

The oldest Tertiary rocks in the North island are of *Eocene* age and consist of coarse conglomerates together with subordinate shales and sandstones. The pebbles in the conglomerates consist chiefly of red and yellow jaspers with some green serpentine. The sandstones have yielded some fossils, including *Nummulites atacica* Leym. and *Assilina granulosa* D'Arch., which occur in the Negrais Group of the Arakan Yoma and in the Eocene Laki Group of Sind, and probably are of Ypresian or Lutetian age. In the Middle Andaman the Eocene beds, consisting of conglomerates, sandstones, and clays, constitute the greater part. The pebbles in the conglomerates are chiefly of quartzites, with some of serpentine and other plutonic rocks. The pebbles and boulders of volcanic rocks and associated beds of volcanic tuffs include olivine basalts and augite andesites; they are not altered to the same extent as the plutonic peridotites and serpentines, and may indicate a pre-Eocene period of vulcanicity³². In the beds of clay there are pockets of coal with plant-remains, as in the Brown Coal Series on the Nicobars. In the South island blue-grey micaceous or calcareous sandstones with intercalated shales predominate, and conglomerates are rare; only some leaf-impressions have been found in them. It is believed that these beds represent the conglomerates of the North island and are also Eocene. Definite volcanic ashes³² appear to occur at the base of the sandstones, and earlier lavas of an andesitic and basaltic nature are indicated by fragments and pebbles in the sandstones.

Miocene beds exist on some of the islands off the west coast of the Middle and North Andamans, and the rocks, which are chiefly composed of foraminifera and calcareous algae, vary from a compact limestone to clays, soft sands, or shelly marls. They rest directly but unconformably on the Eocene conglomerates. *Nummulites nias*

Verb, is extremely abundant, but a species of *Placenta* and one of *Pecten* are also common, and resemble forms in the Miocene Gaj Group of Cutch, while the general facies of the fauna is like that of the Miocene of Burma.

The Ritchie's Archipelago³² off the east coast of the Andamans has its strata composed of soft non-calcareous clays containing radiolaria and sponge-spicules. Oldham termed them the 'Archipelago Series,' but their age is uncertain, though Tipper provisionally put them with the Miocene. Lithologically they bear a striking resemblance to the Nicobar rocks, which contain similar but more abundant and varied fossils. On Outram Island³² ferruginous shelly sands contain marine mollusca, etc., which suggest a later Tertiary age for this deposit. Raised beaches³⁵ are a conspicuous feature on many of the islands, and Recent oscillatory movements seem to have taken place.

The structure of the Andamans is described by Tipper as that of an anticline which has been thrust or folded over to the west, and the steeper westward descent of the sea-floor seems due to a fault. Coal of poor quality occurs in pockets in the Eocene sandstones.

Rutland Island and the Cinque Islands³² are chiefly composed of the altered peridotites (serpentes), with some sandstones and shales in parts like the Port Blair (Lower Tertiary) Series.

The Nicobar Islands

The rocks^{23-25 32 35} which this group of islands is composed are believed to be of the same age as those in the Andamans⁶, which lie to the north of the Nicobar Group. The so-called 'Brown Coal formation' of Dr. Rink, which consists largely of fine-grained micaceous and calcareous sandstones and shales, with scattered fragments of fossil wood, is regarded as corresponding to the Eocene Series, but it is more strongly disturbed and folded. These beds are found mainly developed in the middle islands, where they form bare hilly ranges 2500 ft. in height. The statement that these Eocene beds are affected by intrusions of serpentine and gabbro has been doubted, as there is no evidence in the Andamans that such igneous intrusions affect the Lower Tertiary, and we may suspect that some of the beds should rather be classed with the Serpentine (pre-Tertiary) Series of the Andamans. The younger series of rocks, probably corresponding to the Archipelago or Miocene Series of the Ritchie's Group, is found only on the islands of Nancowry, Trinkat, Camorta, and those lying to the north, and consists of soft grey calcareous clays containing radiolaria¹⁶, with interbedded conglomerates which are almost entirely composed of igneous boulders **and** sandstones, containing fragments of lamellibranchs

and foraminifera. These younger beds are only slightly tilted, and are generally found in association with the serpentine rocks in the northern half of the islands.

Barren and Narcondam Islands

Both these islands³¹, which lie in the Bay of Bengal, are of volcanic origin; Barren Island was in eruption in the eighteenth century, but in Narcondam there is no trace of such recent activity.

Barren Island^{9-11 31} consists of a curved marginal ridge, 700-1000 ft. high, broken down on the western side to the sea-level, and enclosing an oval amphitheatre about a mile in diameter, in the centre of which is a regularly formed cone over 1000 ft. high, bearing a crater with solfataras. The encircling ridge is formed of beds of lava, scoria?, ash, and agglomerate dipping seawards, and must be regarded as the remnant of a great volcanic mountain, the centre of which has been blown away by a paroxysmal eruption, subsequent to which the present central cone was built up. The lava-flows forming the outer ring are of basalt and andesite. According to Washington³¹ the lavas are chiefly augite-andesites with some olivine-free basalts. In the amphitheatre and around the foot of the cone are later scoriaceous lava flows of essentially the same character, one of which must have poured out through the breach into the sea.

Narcondam 9 31 is a mountain of roughly conical shape, about 2200 ft. high, and has no crater. The surface and cliffs have been deeply worn by long denudation. The lavas are more acid than those on Barren Island, and there is little or no ash. Washington³¹ terms the lavas hornblende-dacites.

The volcanic arc to which these islands belong stretches south through the Malayan islands, and is the same as that on which stands Mount Popa in Burma.

Mergui Archipelago

(See chapter on India and Burma.)

Christmas Island

Christmas Island^{12 29 30} is situated in the Indian Ocean in 10° 25' S. lat., 105° 42' E. long., about 190 miles south of Java, and rises steeply from water of great depth. It forms the flat summit of a submarine mountain, probably of volcanic origin, rising more than 15,000 ft. from the sea-floor. The central portion of the island is composed of an elevated plateau over 1000 ft. above sea-level, and it descends on all sides by a succession of terraces which are separated by slopes or cliffs.

Geologically it is composed of marine limestones ranging in age from Eocene to recent reef-formations, but amongst the older beds various volcanic rocks³⁰ are interstratified. The greater part of the island appears to be composed of Miocene Orbitoidal limestone.

The oldest limestone, which is about 140 ft. thick, contains many foraminifera (*Heterostegina depressa*, *Orbitoides*²⁹ (*Discocyclus*) *oceanica*, etc.), and is of Eocene age. Associated with it are flows of trachyte and basalt³⁰. These volcanic rocks³⁰ separate it from the Miocene limestone, about 160 ft. thick, which contains fragments of them, and is characterised by *Lepidocyclus neodispansa*,* species of *Miogyopsina*²⁹, *Miliolina trigonula*, etc. But there is also a series of Miocene lavas resting on the Eocene limestones. The earlier Eocene or pre-Eocene volcanic³⁰ rocks comprise alkali-trachytes, trachy-basalts of more than one type, olivine- and nepheline-basalts and limburgite. The later lavas of Miocene age are limburgite basalts and olivine basalts, with palagonite tuffs, and much resemble some rocks from New South Wales.

The next beds in chronological order are masses of talus covered by a thick detrital limestone derived from the waste of the reefs on the higher parts of the island, and the base of the cliffs and slopes which are formed by this limestone is in turn covered by later reefs of Pleistocene or Recent age. Various post-Miocene coral reefs and limestones containing foraminifera and *Lithothamnion* occur also on the central plateau. In several parts of the island the limestones have been phosphatised by deposits of guano, and most of the limestones are more or less dolomitised.

The whole succession of beds points to many movements of elevation and subsidence. A closely similar succession of Tertiary limestones and intercalated volcanic beds is found in Java, but the foraminifera contained in the beds are rather different.

Keeling or Cocos Islands

These islands^{3 38}, about 20 in number, form a group about 700 miles south-west of Sumatra, and are entirely of coral formation. Keeling Atoll is a characteristic atoll described in detail by Darwin³.

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SECTION IV.—HONG KONG

The colony comprises the island of Hong Kong, the peninsula of Kowloon on the mainland, and various neighbouring islands.

The island of Hong Kong appears to be almost wholly composed of igneous and plutonic rocks, and to be a fragment of an ancient plateau ; but sedimentary formations also occur. The mountains have been described as consisting mainly of granite, serpentine, and syenite. Flows of basalt, occasionally possessing columnar structure, have been observed in some places, and dykes of basalt are stated to pierce the granite.

Recently much fuller information about its geology and the formations represented has been obtained, though the ages of the different rocks are matters of dispute. Schofield⁵ states that the greater part of the centre of the island, including the Peak, consists of felsitic lavas and tuffs of Permian age, while the intrusive granite - porphyry is of Cretaceous age, but the main mass of the granite belongs to the Tertiary. Pendants of andalusite rocks are stated to occur in the granite in isolated patches. The stratigraphical succession of the sedimentary rocks has been drawn up by Heanley⁶, who recorded the first fossil which was identified by Grabau⁸ as the Spiti Shale ammonite *Hoplites wallichi* (Gray), but this determination has been rejected by Buckman (see below). The series of beds recognised by Heanley is as follows :—

Formation 4. Sandstones and conglomerates.

„ 3. Red shales, red conglomerates, and red sandstones.

(Unconformity)

„ 2. Sandy shales with *ammonites* and plant-remains. Massive bedded conglomerate of white quartz pebbles and sand.

„ 1. Dark crystalline schists with some crystalline limestone.

The fullest and latest description of the stratigraphy and palæontology of Hong Kong and the territory on the mainland has been given by Williams¹¹. The succession of rocks which he gives is as follows:—

Miocene ? (*Rocky Harbour Group*, of granites, dykes, volcanics).

Eocene ? (*Mirs Bay* red sediments, with plant-remains.)

(**Laramide revolution.**)

Cretaceous (*Shelter Bay* volcanics.)

(Jurassic revolution with grano-diorite and porphyry intrusions.)

Jurassic ? (*Repulse Bay* volcanics (with corals in tuffs)).

Liassic (*Tolo Channel Group* (sediments with some volcanics)).

Permian (boulders of limestone in later volcanic agglomerates).

The only recognisable fossils are : (1) A few ammonites in the Tolo Channel beds belonging to the Jurassic group of *Schlotheimia*, and put in a new genus *Hongkongites*, and considered to indicate a Lower Lias horizon, according to Buckman, but previously regarded by Grabau⁸ as Lower Cretaceous. (2) Plant-remains in the same group of beds belonging to the genera *Pterophyllum*, *Cladophlebis*, etc., and likewise indicating a Lower Jurassic or Liassic age, according to Seward. (3) An unidentified coral from the Repulse Bay volcanic tuffs, allied probably to *Archceoseris* of Jurassic age. (4) Foraminifera of the genera *Fusulina* and *Fusulinella* in the limestone boulders in volcanic agglomerates, pointing to the existence of Permian beds. The Tolo Channel Group includes the Pat Sin conglomerates which are widely spread, as well as argillites, grits, shales, sandstones, with some volcanics, etc., which have in places suffered considerable metamorphism by the later successive intrusions of igneous rocks.

Kingsmill² described a belt of stratified rocks consisting of slates and quartz-rock entangled in the granite and stretching across the island W.N.W.-E.S.E. in a strip 2 miles wide. The beds are said to strike east and west, and to dip at 80°, and the slates from which he recorded the occurrence of 'fossil shells' were referred by him to the Silurian. Bailey Willis³ considers Hong Kong to be situated in an area of old (? pre-Cambrian) rocks where marine deposits were not laid down in Sinian (Cambro-Ordovician) times. Granite is quarried on the neighbouring Kowloon Peninsula, but the geology of the adjoining leased territory (376 sq. miles in area) has not been completely investigated.

'The whole colony, including the mainland peninsula, is traversed by a series of parallel mountain-lines running from north-east to south-west, . . . and between these mountain ridges is the Tolo Channel⁴.' A series of bays trending north-west and south-east also indents the margin, and these bays tend to occur along parallel lines. Two sets of fractures intersecting at right-angles, such as are typical of fiord-districts according to Gregory⁴, may be suspected to account for these features, but intense sub-aerial weathering owing to the excessive rainfall and the drowning of the valleys by later submergence have modified their characters.

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CHAPTER XIII

AUSTRALIA

General Characters.—Three main natural divisions may be recognised in Australia, based on physiographical characters and geological structure^{4 55a} :—

1. The Eastern Highlands or coast ranges of eastern Australia which run in a general north and south direction, parallel to and not far from the eastern coast-line, and stretch from Tasmania to Cape York and across Torres Straits into New Guinea, form one division. These ranges are not a true cordillera like the Andes, but are the worn-down base of an old mountainous region, and have had a varied geological history. They slope down on the west to the interior plains, and on the east descend to the sea in a series of step-faults or monoclinal folds.

2. The Great Plains which constitute the second division extend from north to south from the Gulf of Carpentaria to the basin of the Murray River, and are mostly an area of internal drainage. They mark the extent of a great mid-continental sea in Cretaceous times. At the south end of these plains are (a) the South Australian Highlands²⁸² of older rocks stretching northwards from the coast to Lake Eyre, (b) the Murray-Darling Basin, and (c) the tectonic trough or rift valley known as the Great Valley of South Australia^{251 252}, separating the South Australian Highlands from the third division, and extending northwards up Spencer's Gulf to Lake Torrens.

3. The third division, which is known as the Western Plateau, constitutes more than half of the continent, and is composed of a mass of ancient rocks, mostly Archaean or Pre-Cambrian, which have been exposed to sub-aerial denudation since early geological times. It rises now to a height of from 1000 to 1500 ft., and comprises the whole of West Australia, and most of the Northern Territory and South Australia.

The general geology of *Victoria* has been described by Skeats²²⁶, of *South Australia* by Howchin⁷¹ and Fenner²⁵², of *Western and Central Australia* by Maitland and Montgomery⁷⁴ and Jutson⁸³⁵, of *New South Wales* by Sussemilch^{12 209}, and of *Queensland* by Whitehouse^{227 262}. A sketch of the geology of the *Northern Territory* has been given by Voisey^{208 286}, and of *Central Australia*

by Cbewings²⁹¹ and Ward^{85 311}. But the latest general review of the geology of the whole continent is that given by David¹¹⁸.

General Geological Structure and History^{1-5 97118187}.—To the west of a line drawn from the south-west of Tasmania to the middle of North Queensland, the greater part of the Australian continent is composed of Pre-Cambrian or Archaean rocks of which the prevailing strike is from north-west to south-east. These rocks form the Western Plateau, most of which has been a land-area and unsubmerged since Middle Palaeozoic or even earlier times, except along the margins, so that it has received no covering of later marine deposits.

Possibly at the end of the Pre-Cambrian period a land-surface occupied also the south-eastern or even the whole eastern side of the continent, for the schists of Cloncurry in northern Queensland and the gneisses and schists of eastern Victoria may be of Pre-Cambrian age. In contradistinction to the Western Plateau this region has subsequently suffered repeated tectonic disturbance.

There is a large spread of Lower and Upper Palaeozoic rocks in the north-western portion of the continent, and along the western margin Mesozoic rocks form a narrow fringe, while on the Australian Bight in the south a large triangular basin of late Cretaceous and Tertiary rocks (the Eucla Basin) is present. In Central Australia³⁰⁹ in the Macdonnell Ranges^{104 114 125 292} a Cambro-Ordovician sea existed; apparently it did not penetrate westwards, although southwards and south-eastwards there was a large marine area of deposition at that time.

The Eastern Highlands, which constitute the first division, contain rocks of all ages, from Pre-Cambrian to Triassic or Jurassic, but they are not uniformly distributed. This region shows repeated movements of submergence and uplift, and there is evidence of more than one period of folding, so that its history is varied, and the succession of events differs from place to place. At the close of the Ordovician there were especially powerful folding movements, but in Silurian times a fresh depression allowed a shallow sea to spread westward almost to Broken Hill. Another period of folding ushered in the Devonian, and then sedimentation set in over a still narrower area. A noticeable tendency prevailed for Australia to grow northward and eastward, the marine transgression becoming progressively less towards the west and south.

Before Carboniferous times there was an uplift towards the south, so that the marine Devonian is missing in Tasmania, but in northern New South Wales the Carboniferous and Devonian are conformably developed.

The Pemo-Carboniferous marks a time of marine submergence

of wide marginal areas not only in eastern Australia, but also in southern and western Australia. Terrestrial and fresh-water conditions, however, prevailed during long intervals. The movements which took place after the deposition of these beds caused strong folding only in a narrow area on the eastern side of the continent north of the Hunter River and in West Australia, the beds elsewhere being only slightly disturbed or horizontal.

The Trias-Jura period was marked by a further depression affecting two area in the Eastern Highlands, each of which possessed distinctive features, the southern or Hawkesbury area being separated temporarily from the northern or 'southern Queensland-Clarence' area; but no invasion of the sea took place, and only fresh-water or estuarine basins of deposition were formed. The great artesian basin^{36 72} began to be formed in Triassic-Jurassic times by broad warping of the then existing surface, and this downward movement increased in Cretaceous times, so that marine conditions then prevailed and thick deposits accumulated. Later upward movement brought in lacustrine and terrestrial conditions.

Cretaceous times witnessed the transgression of the land-areas by a great epi-continental sea extending southwards over the central region between eastern and western Australia, which is now occupied by the Great Plains, but it did not reach farther south than the northern end of Lake Torrens, and the Eastern Highlands seem to have formed a mass of land which, together with the western division of the continent, suffered sub-aerial denudation and peneplanation. Some marginal Cretaceous marine deposits were laid down on the Queensland coast, and though these have suffered some post-Cretaceous folding, it is noteworthy that there is no evidence of any great orogenic movement in Tertiary times in Australia, as in most other parts of the world. The sea subsequently retreated from northern Australia, but began to encroach on the south and spread far inland in gulfs, in which Tertiary marine deposits were formed. The Eocene sea was apparently limited to comparatively small areas in the south of the continent, and the later Tertiary (Miocene) marine beds point to the same conditions, for they are also of small extent and confined to much the same areas. A series of epeirogenic uplifts appear to have affected the continent as a whole in post-Cretaceous times, but special locally restricted vertical movements also took place, as for instance in Victoria²²⁶. Fresh-water lacustrine deposits were formed over large districts, but the most conspicuous feature of the middle and later stages of the Tertiary was the outpouring of great streams of basaltic lava in south-eastern and north-western Australia. A collapse of the marginal **segments** leading to a reduction of the land-area of Australia also **took place** along great fault lines which were chiefly meridional in

direction and stretched along the eastern side of the main divide, but the interior basin was probably formed by the gentle warping of the crust. The formation of the long rift valley (the **Great Valley of South Australia**) holding Spencer Gulf and extending far inland probably also dates from these late Tertiary times, **and** the depression of the Lake Eyre Basin in the interior began **about** the same date, thus forming a vast inland lake below sea-level in which were deposited the loams and other sediments containing the extinct marsupials, fish, and birds of this region.

According to David^{15 118 187}, all the principal orogenic movements of the continent took place before Mesozoic times, no true folding (except in Queensland and in the direction of New Guinea, where Cretaceous and early Tertiary strata are much disturbed or even strongly folded) having occurred since that date. In fact, the latest of the true fold-mountains of Australia had their origin in the Carboniferous period^{5 97}. In Western and Central Australia no folding of the rocks of any great extent has taken place since Pre-Cambrian times¹¹⁸, and there are no young mountain ranges in Australia.

The orogenic movements up to near the end of the Palaeozoic were largely in the form of S-shaped spirals, indicating a tendency of the earth's crust to fold itself in two directions, making a wide angle with one another^{15 187}. The later movements were mostly of the nature of broad warpings or great fractures, and, as mentioned in the foregoing sketch of the history of the continent, many of the faults were not formed till a late Tertiary or even post-Tertiary period. Amongst the newest faults are those which have broken into blocks the Flinder's Range³³⁸, the main Eastern Divide, and the Darling Ranges of West Australia. The folds of the Macdonnell^{85 104 118 187 292} Ranges form arcs convex southwards with a general east-to-west direction, and farther south there are the concentric arcs of the Musgrave and other ranges. But the western part of the Plateau is traversed by folds with a general N.N.W.-S.S.E. trend. In the Flinders³³⁸-Mount Lofty areas of South Australia the folds are chiefly meridional, but in eastern Australia and Tasmania the direction of the folds is mainly N.N.W.-S.S.E. The folding movements in the latter region are more diverse and belong to more than one period, and some cross the older folds at an angle. For in eastern Australia there were several minor and mostly local epochs of folding during Devonian, Carboniferous, and Permian times, and David¹¹⁸ has pointed out important epi-Permian movements in certain parts. Except in some regions of Queensland orogenic as distinct from epeirogenic movements seem to have ceased after the end of Palaeozoic times^{187 206}. We may here remark that, according to Benson²⁴⁷, there is generally a definite association

of special types of basic and ultrabasic intrusions with the several tectonic movements.

The coastal physiography⁸⁹ is to a great extent in close relation to tectonic lines. Thus the Gulf of Carpentaria has its eastern, southern, and western shores determined by fold-axes of the rocks, and on the south coast of the continent Spencer Gulf and St. Vincent Gulf are sunken troughs or fiords at the southern end of the above-mentioned great rift valley of South Australia, while Bass Strait and Torres Strait are likewise regarded as rift valleys. Both the Atlantic and Pacific types of coast are developed in Australia, the former being found along the whole of the north-west shores of the continent, and the latter along the north-east of Queensland. But the eastern coast is a special type, as Gregory has pointed out, and is due to subsidence on the inner side of a curved fold-mountain-chain of which New Zealand is an outlying fragment. This subsidence produced the Tasman Sea and the Coral Sea, and the East Australian Plateau descends into these basins by a series of step-faults or monoclinical folds of late geological origin. Along the eastern coast there is a great thrust-plane and overthrust reaching from Townsville to Maitland, the pressure coming from the east^{187 206} and taking effect after Kamilaroi (Permian) times. It is on a sunken strip of the coast that the Great Barrier Reef^{57" 69 201 206 207 210 297} is built, and the foundations of the islands^{201"240 250} inside it along the coast are also fragments of a broken marginal band. Recent sea-level changes²⁵⁵ in eastern Australia seem to have been marked by an earlier eustatic positive movement of the strand-line and a much smaller later negative movement; minor movements of both kinds are locally observable.

Palaeontology.—The characteristic fossils of the various Australian formations in many cases belong to non-European genera or species, and a convenient summary of them is given by Chapman in his book *Australasian Fossils* (Melbourne, 1914), pp. 1-341, to which reference may be made. David¹¹⁸ has, however, pointed out the specific identity of several European and Australian fossils, but we may rather note the identity or close affinity of many of the Permian species in all parts of the Southern Hemisphere, and especially in India and Australia.

DETAILED ACCOUNT OF THE FORMATIONS

ARCHEAN AND PRE-CAMBRIAN (=Archeozoic and Proterozoic)

The series of formations which are included under these names comprise the most important metalliferous rocks in the continent, and practically all the most valuable ore-deposits are found in them^{26 83 89 118}. About one-third

of the whole of Australia is occupied by rocks of this age, which bear many local names.

The main mass of **Western Australia**^{6 8S 7 4 1 2 o 220} consists of a block of such Archaean or Pre-Cambrian rocks passing eastwards into similar areas in Central⁸⁸ and South Australia and the Northern Territory^{16 840}. A full description of some of the principal areas will be found in papers and memoirs by Andrews¹⁴⁰, Clarke¹⁴¹, Condit⁸⁴¹, and in the Bulletins of the Geological Survey of Western Australia. The bulk of the rocks is composed of gneisses, schists, and granites, and there are occasionally beds of scarcely metamorphosed sediments, including clay-slate and quartzite, which often contain oxides of iron to such an extent as to be of the nature of iron-ores. The plutonic rocks have generally been foliated, and many intrusive dykes of igneous rocks pierce the whole complex series. The rocks are nearly always much folded, and have suffered much from faulting and other earth-movements. The classification which is at present possible is mainly lithological, no general uniform sequence in the beds having been established, though locally the succession has been precisely determined. In many parts the rocks are richly mineralised. The main system of folds affecting the rocks in West Australia runs sub-parallel to the coast-line, with a general meridional or north-west to south-east trend, and there is overfolding to the west.

There are three well-defined divisions of the Archaean and Pre-Cambrian²²⁰ in West, Central, and South Australia⁷⁴; the lowest is the *Yilgarn Series*, which consists of schists of various types and of granitic-, biotite-, garnet-, and sillimanite-gneisses. This series is separated from the later *Kalgoorlie Series*¹⁰² by an unconformity. The Kalgoorlie Series consists of 'greenstones' (=basic lavas and tuffs) and of associated metamorphosed sediments. Another unconformity separates this series from the *Mosquito Series*, which includes porphyrites, greenstones, and serpentines, as well as schists, phyllites, and dolomites, with bands of chert and jasper. This Series is largely developed in the Central Goldfields.

At the close of Mosquito time there were great intrusions of granite, especially noticeable in the southern part of West Australia, in the Pilbara area in the Cloncurry district, in the Broken Hill and probably the Mount Lofty regions, though not all the granites are of the same age. In the Stirling Range there is another series of quartzites and reddish slates which form the conspicuous surface feature and may be rather younger than the Mosquito Series. At the close of Mosquito time there was the most important metallogenetic epoch¹¹⁸ in Australia which resulted in the formation of most of the gold-deposits in Western Australia; it was also connected with the intrusion of many of the granites which are traversed by the auriferous quartz-reefs. It is probable that the silver-lead deposits of Broken Hill and the iron deposits of Western and South Australia are referable also to this period.

In the **Pilbara district**⁷ the general succession is well seen. At the base are gneissoid granites, which are the *Yilgarn Series* and the fundamental rocks; on them come amphibolites and hornblende-schists, mica-schists, talc-schists, chloritic-schists, and siderite-schists. These compose the *Kalgoorlie* and *Mosquito Series*. Most remarkable are the banded haematite-magnetite quartz rocks, identical with those in the Indian, Rhodesian, and East Transvaal Archaean areas. These rocks are steeply inclined, and form bands stretching for miles across the Pilbara country parallel to the foliation and direction of the main belts, generally from north-west to south-east, and give rise to serrated ridges⁷⁰. Veins of pegmatite traversing these rocks carry metalliferous veins, and rare earths (e.g. tantalite) are associated with them.

These schists are overlain unconformably by the *Newer Proterozoic*¹¹¹.

which consists of a fairly horizontal and scarcely altered series of sandstones, grits, conglomerates, and dolomitic limestones, associated with abundant igneous rocks, comprising amygdaloidal diabase and felsites, some of which are contemporaneous, but other are intrusive, associated with ashes and breccias. This series of rocks constitutes the *Nullagine System*^{26 61 118 120}, which is said to bear a very marked resemblance to the Transvaal System of South Africa⁸⁸. These rocks have also been compared¹²¹ to the Cuddapah and Kurnool beds of the Indian Peninsula. None of the beds yields any fossil evidence as to their age, but some geologists refer them to the Cambrian. David¹¹⁸ places them in the Newer Proterozoic. The Nullagine Formation is perhaps the most widely spread of any of the rock systems in western Australia, and generally leads to special topographic features, frequently forming plateaux. The basal conglomerate in places contains flattened and striated pebbles, and may be of glacial origin. The volcanic series, which consists partly of acid rocks and partly of dolerites, occurs near the base of the formation, and may reach 500 ft. in thickness. An important group of magnesian limestones occupies a definite horizon, and is several hundred feet thick; it has been termed the Carawine Dolomite, and occupies a large area in the Ashburton and Oakover Valleys and elsewhere. Resting on this dolomite are ferruginous sandstones, quartzites, banded jaspers, and banded iron-ores⁶¹. The basal conglomerate of the formation sometimes carries gold, and auriferous and cupriferous quartz veins traverse the rocks where they have been disturbed.

In the Kimberley Division the beds corresponding to the Nullagine Series are known as the *Elvire Series*, which consists of quartzites, grits, and conglomerates, succeeded by shales and limestones. The beds are disposed in broad anticlinal folds. The corresponding beds in the Macdonnell Ranges⁸³ 204 292 are known as the Pataknurra Series, and in the Flinders³⁸⁸ and Mount Lofty Ranges of South Australia, as the Adelaide Series (see below), if we follow David¹¹⁸ and Mawson²⁷⁷ in referring this series to the Pre-Cambrian. In the Kimberley Division large areas are covered by the overlying basaltic flows with some associated tuffs. These constitute the *Antrim Plateau Basalts*, about 3000 ft. thick, and they extend eastwards from Kimberley into North Australia⁸⁴⁰ and Queensland, and south into South Australia. An unconformity separates them from the overlying Lower Cambrian rocks. Similar basic volcanic rocks extend into Northern Australia⁸⁴⁰, Queensland, and South Australia, bearing different names.

In the **Central Goldfields**⁹ (Peak Hill, Murchison, Yalgoo, and Yilgarn) the schists are penetrated by an older granite which has suffered with them the same dynamic metamorphism, and both are invaded by a much newer granite. As is the case elsewhere throughout West Australia, many of the schists themselves are sheared and crushed basic igneous rocks, some of which are of an intrusive nature, and comprise many different types.

In the **Eastern Goldfields**⁹ of Western Australia there is a remarkable uniformity in the geological structure and in the mode of occurrence of the mineral deposits. The main formation in the district is granite and gneiss, with a partly later series of schistose rocks, some of which are of sedimentary origin, and include the peculiar banded haamatite-bearing quartzite. With them is associated a large development of basic rocks of various types. The general strike of the schists is north-west to south-east, and they are often vertical or steeply inclined. Gold occurs generally at no great distance from granite intrusions and along shear-zones and shatter-belts; the latter rocks are often cut by pegmatites and dykes of porphyry.

In Kalgoorlie⁸¹⁰² and Boulder¹⁹⁸ the rocks comprise (1) an ancient sedimentary series with interbedded lava-flows, (2) older greenstones (oalc schists

and fine-grained anphibolites), (3) peridotites, (4) porphyrites, and (5) quartz- and felspar-porphyrtes. Of these, the ancient sedimentary series consists of shales, sandstones, conglomerates, and boulder beds, associated with igneous rocks (lava-flows, etc.), and they cover a very large area. These were subsequently intruded by large masses of basic and ultrabasic rocks, and finally by more acid rocks. All have suffered considerably from shearing, faulting, and chemical changes which are particularly shown by the extreme carbonating of the quartz-diabases. It is in connection with these altered diabases that the principal gold-deposits occur. The gold is found native, or as tellurides (see 'Economic Geology').

In the region between Kalgoorlie and Coolgardie, and south of Kalgoorlie, the following local succession of Archaean and Pre-Cambrian rocks has been determined¹⁰.

A. KURRAWANG SERIES (slates, arkoses, and conglomerates).

Unconformity.

Intrusive { Norite
Granite.
Porphyry and porphyrite.
Dolerite and gabbro.
Serpentine.

B. KALGOORLIE SERIES

Sedimentary { Sandstone
Slates.
Porphyrites (volcanic), including flows, sills, tuffs, and agglomerates.
Greenstones (volcanic), including tuffs, dolerites, amphibolites, and agglomerates.

G. Old basement granite.

The Kurrawang Series shows no obvious unconformity to the Kalgoorlie Series, but it contains fragments and detritus of the porphyries and greenstones. The beds are often crushed and form conglomerate-schists containing pebbles of quartz and jasper or of slate, quartzite, and porphyry. The strike of the series coincides with that of the Kalgoorlie Series, and both have been folded, faulted, and sheared by several distinct earth-movements. Whether it is of the same age as the Nullagine Series is uncertain. It is stated that there is a striking lithological and structural resemblance between the Kalgoorlie and the Huronian Series of the Lake Superior District.

Passing eastward into the **Northern Territory**^{140 203 338} we find a large expanse of Archaean or pre-Cambrian rocks¹ in the Woggaman Province²⁸⁶ and in Arnhem Land west of the Gulf of Carpentaria, and patches of them occur in other parts of the Northern Territory and Central Australia^{83 85 290 309}.

In **South Australia**^{71 90 118 181} they are well developed in the Musgrave and Maedonnell Ranges^{114 125 204 290 292}, near Lake Gardner, and to the west of Lake Eyre. The Gawler Ranges to the west of Spencer Gulf consist of a great mass of ancient porphyry or granite. Farther south Archaean rocks⁹⁰ are developed on both sides of St. Vincent's Gulf near Adelaide, and they form Yorke's Peninsula, the foundation of the Mount Lofty Ranges²³⁶, and the backbone of Kangaroo Island. In the Maedonnell Ranges¹¹⁴, in the centre of the continent, dolomites and crystalline limestones, as well as schists, gneisses, and granites, are found, and the beds are strongly folded along east and west axes. In these ranges^{104 114 126 204 292 809} there is a basal Archaean series of metamorphosed sediments (gneisses and schists) intruded by masses of granite and dykes of pegmatite and other igneous rocks. This is termed the *ArurUa*

Complex. The post-Arunta rocks are chiefly sedimentary and consist of massive quartzites, crystalline limestones with algal remains, dolomites, and slates which lie unconformably on the Arunta complex. But whether these should all be regarded as Cambrian or Pre-Cambrian is doubtful⁸⁰⁹. Their thickness is over 10,000 ft., and they are overlain by Ordovician rocks of the Larapintine Series (see below). Algae contribute largely to the Pre-Cambrian limestones of South Australia²⁶⁵. The classification, correlation, and succession of all these Proterozoic²⁷⁷ rocks in South Australia have not at present been finally determined. Their precise age is a matter of dispute; while some authorities would place them in the Pre-Cambrian (Newer Proterozoic), others would refer them to the Lower Cambrian. While they mostly consist of highly metamorphosed sedimentary deposits, yet there are also many eruptive masses of an acid or more rarely a basic type amongst them^{263 264}.

The *Adelaide Series*^{118131 251} of rocks in the Adelaide district, which have been mentioned above in connection with the Pre-Cambrian, succeeds a more metamorphosed series of rocks in the Mount Lofty Ranges, termed the Barossa Series²³⁶ by Horsfeld, and this with the *Lower* part of the Adelaide Series may be reckoned as Pre-Cambrian. The *Upper* Adelaide Series contains the organic remains radiolaria, primitive arthropods, annelids, brachiopoda, and algae⁸⁰³, in calcareous and argillaceous deposits, changed into phyllites, and limestones. This formation resembles in its character and contents the Belt Series in Western Canada (*q.v.*), which some would place in the Lower Cambrian. Howchin⁷¹ definitely put the Adelaide Series in the Lower Cambrian, and we are inclined to refer its Upper division to this system. There is a break in the succession before the deposition of the remarkable glacial conglomerate known as the *Sturtian tillite*^{1, 20 71 255 289}, which Howchin^{56 71188 258} regarded as Lower Cambrian, together with the overlying 'Purple Slate Series' of South Australia. This glacial deposit⁷¹ contains sub-angular, angular, and rounded boulders up to 11 ft. in diameter in an unstratified ground-mass, and has a few interbedded bands of slate, quartzite, and limestone in it, the whole series having a thickness in places of 1500 ft., and occurring over an area extending north of Adelaide for over 400 miles. The boulders in it, which comprise granite gneiss, mica-schist, and other rocks, suggest that the ice came from the south-west, but the deposit was probably laid down by floating ice. This glacial deposit, or series of deposits⁷¹, which has been compared by David¹⁷⁸ with the Numees tillite of South Africa, is found well developed in the Flinders Range⁸⁸⁸, where Mawson²⁹⁸ has also described a great series of beds (the Munyallina Series) overlying it in the eastern foothills of this Range. The glacial beds are here 1000 ft. thick, and the shales, limestones, quartzites, etc., make up a total thickness of about 12,400 ft. In the limestone the fossil algae *Collenia*, *Girvanella*, and *Mawsonella* occur. The structure of the Flinders Range has been described by Woolnough⁸⁴⁵, and especially by Mawson^{298 338}. Most of the rocks are of Pre-Cambrian age. In the central and northern Flinders Range the tillites occur on two horizons having 9000 ft. of sediments separating them¹¹⁸, and in other places there are tillites on several horizons. The glaciation is estimated to have extended over an area of at least 60,000 sq. miles. It is of later Pre-Cambrian date than the Nullagine basal conglomerate of the Pilbara Goldfield in Western Australia, which is considered to be of fluvio-glacial origin, and rests unconformably on the Mosquito Series.

In **Victoria**^{81 226 228} the so-called Archaean rocks consist of two blocks of gneisses and schists which form the highlands of Dundas in the west, and the whole of the north-eastern part of Victoria (including the counties of Benambra and Bogong), and much of the highest part of the Victorian Alps.

The age²⁹⁰ of these metamorphic rocks is much in doubt. They have been

described as underlying the Ordovician rocks unconformably, but this is disputed. Some of the igneous rocks are contemporaneous lava-flows, but others are intrusive.

In **New South Wales**^{12 242 261} the Archaean and Pre-Cambrian Systems are represented in the southern parts by gneisses and schists forming a northerly prolongation of this great metamorphic area of Victoria. The best-known exposures are in the Barrier Ranges in the western part of the State¹¹⁸. Here the rocks consist of sillimanite- and scapolite-gneisses, amphibolites, micaceous, talcose, sillimanite-, and chloritic-schists, phyllites, quartzites, and quartz-garnet and quartz-felspar rocks, which together form the so-called *Willyama Series*. The more ancient rocks of the Willyama Series consist of a considerable thickness of thinly-bedded grits, sandstones, and shales, which have been metamorphosed into para-gneisses, schists, quartzites, and slates²⁴². An older and a newer series of intrusive igneous rocks are associated which were accompanied with great orogenic movements resulting in folds of the isoclinal type, as well as in compression and shearing. The newer intrusions comprise granites and the acid and basic dykes of the Broken Hill district. The Proterozoic period includes the group of rocks known as the *Torrowangee Series*, amongst which are tillites, slates, quartzites, limestones, and in places contemporaneous lavas. This series occupies a large area in the northern part of the Barrier Ranges. The tillites are especially noticeable¹¹³. The whole series lies unconformably on the Willyama Series. A large number of intrusive rocks (granites and pegmatites)⁹⁶ pierce the Willyama beds. The region is famous for its ore-deposits of lead and zinc (as at Broken Hill)^{118 222} which occur chiefly in the gneisses and mica-schists. The chief lode²⁴³ lies along the saddle of the anticline into which the rocks have been bent. Commonly the ore-deposit is described as a saddle-lode, and as belonging to the class of 'bedded lodes,' but Gregory¹³ regards it as formed along fault or foliation planes. It contains an enormous variety of minerals (see 'Economic Geology'). The original sulphide ore consists of an intimate mixture of argentiferous galena and zinc-blende.

To the west of Broken Hill are the remarkable chialtolite rocks of Biambowrie and the sapphire-schists of Mount Painter, which are generally referred to the Pre-Cambrian. There are also some other smaller and less known outcrops of schists and metamorphic rocks in other parts of New South Wales, some of which may be of Pre-Cambrian age (e.g. in the Cooma-Kosciusko region; others may be of later date.

In **Tasmania**^{9 87 181 118a 190 248} the old rocks are chiefly found on the western coast, in the south-western and north-western portions of the island, and as a fringe along the eastern coast, but they are not very extensively exposed. They consist chiefly of beds of sedimentary origin, such as mica-, talc-, chlorite-, and quartz-schists, slates, conglomerates, etc., with some gneiss, granite, serpentine, and other intrusives penetrating them; subordinate bands of limestone or dolomite also occur. The largest continuous development of schists is in the west and south of the island, forming lofty ranges running north and south-west of the King William and Denison Ranges⁸⁷.

In the Mount Lyell district^{18 174} the schists are intensely altered quartz-porphyrites, diabase-porphyrites, and acid volcanic tuffs, and in them are developed the 'fahlbands,' or bands of mineralised rock containing copper- and gold-bearing ores.

In the Jukes-Darwin mining field¹⁴ the oldest rocks are quartzites and quartz-schists, but the so-called 'Porphyroid Series,' which may be later than Pre-Cambrian, consists of felsitic lavas, breccias, and tuffs, with associated slates in which occur the ore-deposits (copper, silver, and gold). The rocks

have been folded, metamorphosed, and invaded by granite before Silurian times. By some geologists they are correlated with the Heathcote Series of Victoria (see 'Cambrian').

The chloritic-schists and serpentine which are associated with huge deposits of haematite and magnetite on Mount Heemskirk, Mount Cleveland, and the Ironstone Hills, near Beaconsfield, may also belong to the Archaean or Pre-Cambrian.

In **Queensland**^{24 227} the precise geological age of many of the metamorphic and plutonic rocks is at present a matter of dispute or uncertainty, and some at any rate are probably altered Palaeozoic rocks. Thus the age of the *Brisbane Schists*^{211 223 329} has been variously ascribed to dates from Pre-Cambrian to Permo-Carboniferous. But these schists form a succession of rocks of different character, as Denmead²¹¹ has described, and they include a greenstone series followed by mica-phyllites, greywackes, phosphatic beds, and a jasper series. Radiolarian jaspers²⁶⁰ occur amongst them. The metamorphic rocks occur in four main areas:—(1) Cloncurry³²⁹ Goldfield and Mackinlay district in the extreme west of the state, (2) Charters Towers and Cape Goldfields, (3) Gilbert, Woolgar, and Etheridge Goldfields, and (4) the east side of Cape York Iⁿinsula. Many of the associated granites and intrusive rocks (diorite, porphyry, etc.) are undoubtedly of much later date, some being Carboniferous, and others even Jurassic. In the Cape Goldfield there is found a lower series of gneisses, mica-schists, and hornblende-schists, and an upper series of quartzites, slates, and schists.

The Aguilar Range, north of Brisbane, which consists of glaucophane-schists, may also be of Pre-Cambrian age.

In all parts of Australia, these Archaean and Pre-Cambrian rocks are the great storehouse of the principal ore-deposits^{103 176} of the continent, including gold, silver, lead, copper, tin⁷⁵, etc. (see 'Economic Geology').

CAMBRIAN¹¹⁸¹³¹

The fullest development of beds of this system, so far as known, is found in Queensland, South Australia, and in the Northern Territory, but they have been proved to exist in all the States, though in "New South Wales no definite Cambrian fossils appear to have been found. The geographical distribution of the fossiliferous Cambrian in Australia has been summarised by Howchin¹⁸⁸.

In **Western Australia**¹⁶ the plateau of the Kimberley district in the extreme north-east of the State consists of Cambrian rocks exposed beneath Carboniferous beds. This belt of Cambrian rocks stretches from north-east to south-west, but the strike of the beds is from north-west to south-east, and the folds have the same trend. The series consists of crystalline limestones, sandstones, grits, quartzites, flags, and clay-slates. In some parts of these beds there have been found a species of *Redlichia* and also of *Oirvanella* and of *SaHerelfa*¹⁵⁴. Some geologists attribute the Kullagine Series (above described) to the Cambrian instead of to the Pre-Cambrian, but so far no fossil evidence has been produced in support of this view.

In **Queensland** and the **Northern Territory**²⁰³, in Arnhem Land and on the Barclay Tableland, the Cambrian rocks are largely composed of limestones which are often rich in *Galatella*, and overlie thick sheets of apparently contemporaneous basic lavas. Etheridge described a species of *Ohndlus* from these Cambrian beds, and near Elkedra, 150 miles south of Alexandra, the occurrence of species of *Agnostus* and *Microdiscus* also signify the presence of deposits of this period.

In Queensland Whitehouse^{107 107a 118} has recognised in the basins of the Georgina and Templeton Rivers a succession of beds containing Lower, Middle, and Upper Cambrian horizons characterised by trilobites. The Lower, or *Templeton Series*²⁹, is divided into several stages by means of the trilobites, the lowest of which is the *Redlichia* stage. The three succeeding stages are characterised respectively by the genera *Amphoton*, *Inouyella*, and *Dinesus*. The *Georgina Limestone Series* is divisible into many stages marked by species of trilobites (especially by genera of the Agnostidae), and contain also brachiopods, and in the uppermost, or Ozarkian stage, the cephalopod *Ellesmereoceras*. From the Middle Cambrian Whitehouse²⁵⁷ has also described a peculiar primitive echinoderm. Limestones represent these Middle and Upper Cambrian horizons, and extend over a wide area, and twelve miles west of Mount Isa^{108 170}, on the Thornton River, trilobites and brachiopods have been collected from them.

In South Australia^{83 131 133 188}, especially in the South Australian highlands, beds of this system have their greatest development on the continent and occur at intervals from the south to the north of the State⁷¹, stretching into Central Australia and thinning out against the western Pre-Cambrian plateau. In all cases they rest with a great unconformity on *tae* Pre-Cambrian rocks. In Yorke's Peninsula, in Mount Lofty²³⁶, in the ranges behind Adelaide, and thence north to Beltana in the highlands to the west of Lake Torrens, they have yielded a rich Cambrian fauna. Howchin⁷¹ included in the Lower Cambrian the Adelaide Series and the Sturtian tillite. But, according to Whitehouse^{107 107a}, the oldest Cambrian beds with definite Palaeozoic fossils³⁰⁸ (apart from the disputed Adelaide Series and Sturtian tillite) are the *Archaeocyathine Limestones*⁷¹ which, in Yorke's Peninsula and the Flinders Range³³⁸, are strongly developed and are marked by the presence of the peculiar group of sponges comprising *Archaeocyathus* and allied genera¹⁴³. In the eastern Macdonnell Ranges^{86 204 292} (now put in Central Australia) there is a great development of these Archaeocyathine Limestones¹¹⁸, where they are probably several thousand feet in thickness. The next stage in the Lower Cambrian in South Australia is termed by Whitehouse the *Protolenoid Stage*, and is characterised by the trilobite genus *Howchinella*. This stage is found in Yorke's Peninsula. The *Redlichia Stage* is put next by Whitehouse as the highest Lower Cambrian. In the Flinders Range²⁶⁴ the *Redlichia beds* of the Lower Cambrian are seen to be stratigraphically above the Archaeocyathine Limestones, and the *Obolella Stage* in this Range is placed at the base of the Middle Cambrian. The trilobites have been described by Etheridge⁷⁷ and others.

The foundation of central Victoria consists of a series of rocks known as the *Heathcotian Series*^{217 226}, which some geologists would refer to the Cambrian^{5 29-31}, or even to the Ordovician. The Heathcotian Formation²¹⁷ appears to have a mixed Cambro-Ordovician fauna¹²⁸, but some geologists^{122 218 226} would place it in the Middle Cambrian, and others in the Lower, or even Upper, Ordovician¹²⁸. Peculiar hydroids²⁴⁵ occur in the Heath cote, area, associated with Middle Cambrian trilobites. This series consists of phyllites, schists, foliated diabases, amphibolites, trilobite-bearing shales, beds of black chert with *Protospongia* and radiolaria¹²⁸, volcanic agglomerates, and contemporaneous basic lavas, together with intrusive porphyries, microgranites, and granophyres, and they constitute the whole of the Colbinabbin Range eastwards from Bendigo. At the Dolobrook River, North Gippsland, an Upper Cambrian limestone interbedded with basic tuffs has yielded trilobites⁷⁷ (*Agnosius*, *Crepicephalus*, and *Ptychoparia*) with *Scenella* and crinoid stems. Associated are massive serpentines.

Cambrian rocks occur also near Mansfield, where *Olenellus* and *Salterella* have been collected, associated with phosphatic limestones and wavellite.

In **New South Wales**, though no Cambrian fossils have yet been found, there are certain strata in the Barrier district which are lithologically identical and geographically continuous with the Cambrian of South Australia. They include slates, quartzites, limestones, dolomitic limestones, and glacial boulderbeds (tillites). These tillites range up to 800 ft. in thickness, occur at the base of the series, or are regularly interstratified with the other sediments, and rest unconformably on the undisputed Pre-Cambrian¹².

In **Tasmania** in the Mersey district^{32 37} three groups of strata of presumably Cambrian age have been recognised. The *Caroline Creek Series* of Upper Cambrian age has been reported to yield *Asaphellus*, *Tsinania*, *Crepicephalus*, etc.^{77 325}. The generic determination of these trilobites has been questioned²¹², and the faunas of the Mersey River and elsewhere have been referred to the Lower Ordovician⁸²⁵ rather than the Upper Cambrian (see p. 571). The *Dundas Slates*, containing *Hurdia*, as well as the older limestones of Beaconsfield, are referred to the Cambro-Ordovician. The *Dikellocephalus Group*, which consists of quartzites, fine gritty sandstones, clay-slates, etc., and has yielded species of *Dikellocephalus*, *Ptychoparia*, and *Raphistoma*, suggests an Upper Cambrian or Cambro-Ordovician age and a comparison with the Potsdam Sandstone of North America.

The 'Tubicular Sandstones' and quartzites occurring at Mount Zeehan, the Loddon River Valley, Middlesex, and elsewhere, which possess some indeterminable fossils, are also frequently referred to the Cambrian, but the age of these beds is somewhat doubtful. An extensive conglomerate known as the 'West Coast Range Conglomerate' overlies these sandstones in places, as, for instance, at Mount Zeehan and in the West Coast and Denison Ranges³⁷; it is composed of quartz and quartzite pebbles, but so far only obscure annelid borings have been found in it. Where it rests on the Pre-Cambrian schists, it does so unconformably, and contains pebbles of these rocks. It has been subjected to great disturbance and much faulting. In the Mount Lyell district, where this conglomerate has suffered from great overthrusts, a Devonian age has been ascribed to it by some geologists, but its true stratigraphical position is a matter of dispute.

As above mentioned, the Porphyroid Series of schistose quartz-porphyrries, etc., of the Leven Gorge, Dundas¹⁸⁸, may be possibly of Heathcotic, and therefore (according to some geologists) of Cambrian age. The felspathic schists of Mount Lyell are often referred to the Cambrian or even early Ordovician.

ORDOVICIAN¹²²

A discussion of the age of the Ordovician shelly faunas of Australia has been recently instituted by Kobayashi¹²², and their correlation with those of other parts of south-eastern Asia, America, and Europe has been attempted, but our knowledge of the Ordovician of the south-western Pacific Province is inadequate for any final conclusions. The Ordovician rocks of Eastern Australia have been generally closely folded, especially in Victoria. The richest gold reefs of eastern Australia are associated with beds of this age. The intrusion of large plutonic masses took place in late Ordovician times. The fullest development of the Ordovician rocks, which has so far been worked out in Australia, occurs in **Victoria**^{27 28 31 86 226 306}, where they consist of slates, quartzites, and greywackes, all of which have been much folded and mostly highly cleaved. The fossiliferous beds have a graptolitic facies. Some of these rocks, such as those around Ballarat and in parts of the Pyrenees,

as well as the schists around the granites of Ararat, may, however, prove to be of earlier age.

The Silurian and Ordovician graptolitic rocks^{100101198 215 233} in Victoria are together estimated to occupy an area of about 20,000 sq. miles. The Ordovician overlies the Cambrian conformably and prevails west of a line drawn from Melbourne to Heathcote, and is divided into an Upper and Lower division. In the Lower division four formations have been recognised, named respectively the *Darriwill*, *Castlemaine*, *Bendigo*, and *Lancefield Series*. The *Lancefield Series* is the oldest, and consists of blue-black slates containing a strange intermixture of graptolitic genera, *Bryograptus*, *Leptograptus*, *Didymograptus*, *Tetragraptus*, *Clonograptus*, *Dictyonema*, etc., being recorded. The *Bendigo Series* is of considerable thickness, and in it are found *Tetragraptus fruticulosus*, *T. serra*, *Phyllograptus typus*, *Didymograptus caduceus*, etc. The *Castlemaine Series* overlies the *Bendigo* conformably, and contains much the same fauna; the species *Loganograptus logani* here appears, but *Tetragraptus fruticosus* is absent, and *Didymograptus brfidus*, which was rare, is now common. The *Darriwill Series* is marked by the appearance of *Lasiograptus* and *Glossograptus*. Some genera from the lower beds also persist. All these series are held to be of Arenig Age¹¹⁸. A revised classification and correlation of the Graptolitic beds of Victoria has been lately proposed³⁰⁸, but is not here adopted.

The Upper Ordovician division stretches north from eastern Victoria for 300 miles into New South Wales, and is characterised by the presence of *Dicranograptidæ*, and such species as *Dicranograptus ramosus*, *Dicellograptus morrisi*, *D. elegans*, *Climacograptus bicornis*, and *Diplograptus foliaceus* have been found in the beds. A general account of the graptolites has been given recently¹⁰¹¹⁹³ by Keble²¹⁶ and others²⁸³.

The presence of fossils other than graptolites appears to be rare, but species of *Porambonites*, *Siphonotreta*, *Lingula*, *Hymenocaris*, and *Lingulocaris* are known, and in North Gippsland in the Mount Wellington district a dark bluish limestone has yielded species of *Agnostus*, *Cheirurus*, and *Proetus*.

The Ordovician rocks in Victoria are traversed by the principal gold-bearing quartz-reefs, and are covered by the most extensive and richest auriferous gravels; in the Mansfield area they contain important interbedded phosphate rock¹⁷².

In **New South Wales** the Ordovician^{100 128}, which extends northwards from Victoria in a broad belt east of Mount Kosciusko and is here also marked by valuable metalliferous deposits (see 'Economic Geology'), occurs in the southern and central tablelands at numerous localities which are apparently arranged on several north and south axial lines. In the Lyndhurst goldfield clay-stones containing graptolites¹²⁸ (*Diplograptus*, *Dicellograptus*, *Climacograptus*, etc.) occur associated with a huge development of interbedded basic tuffs and thin bands of radiolarian limestones, all of which are intruded by dykes and sills of diorite and augite-andesite. In the Cadia district typical graptolitic carbonaceous shales are associated with claystones, sandstones, andesitic tuffs, and andesites, and a great bed of iron-ore, 60 ft. thick, lies between two sheets of andesite. At Taliong there is a thick series of carbonaceous shales, slates, and quartzites, which are intensely folded and unconformably overlain by the Silurian, and the existence of this unconformity between the Ordovician and Silurian seems to be a feature in New South Wales. In the Tweed River district, thin veins of turquoise (hydrous phosphate of alumina) occur in slates of possibly Ordovician age.

The huge ironstone deposits (Iron Knob¹⁰⁰ and Iron Monarch) to the west of Port Augusta in **South Australia** are probably of the same age as those in the Cadia district of New South Wales.

In **Queensland**²³ the *Toko Series*^{107 329} contains a rich cephalopod fauna (*Actinoceras*, *Deiropoceras*, etc.) in a limestone followed by sandstones with asaphid trilobites. This series extends into the Northern Territory. There is also in that State a 'Greenstone Schist Series' underlying the '*Bunya*'²²⁹ Series' of mica-phyllites, probably 18,000 ft. thick, which has only yielded a *Diplograptus*, and both may be of Ordovician age. Some of the pre-Devonian schists of the Queensland goldfields may also possibly be of Ordovician age.

In the **Northern Territory** and Central Australia the Ordovician is developed in the Macdonnell^{114 125 143 204}, Musgrave, and in some ranges of the Western Plateau, and consists of sandstones and quartzites, and in some places of shale with thin bands of fossiliferous limestone. These beds are said to rest unconformably on Cambrian (?) strata, and have their axes of folding striking east and west. Eastwards they extend into Queensland.

In **Central Australia**^{71 118 143} the series is chiefly arenaceous, with a thickness of 7000 ft., and has been termed the *Larapintine Series*⁷¹. The facies is not graptolitic, and the fauna consists chiefly of cephalopods, mollusca, and brachiopods, with a few trilobites. There are species of *Asaphus*, *Orthis*, *Isoarca*, *Raphistoma*, *Orthoceras*, *Endoceras*, etc., and the fauna seems to indicate the middle part of the Ordovician¹¹⁸.

In **Western Australia** the *Townsend Range Series*⁸⁹ of calcareous grits and conglomerates associated with volcanic rocks (basalts and tuffs) is referred to the Ordovician.

In **Tasmania** the actual sequence of the Ordovician rocks is not ascertained; generally they have been divided into the 'Auriferous Slate Group'¹²⁵ and the 'Gordon River Group,' but the latter is now placed in the Silurian. The former group is extensively developed in County Dorset in the north-east corner of the island, and consists of soft black and blue slates, grits, sandstones, and conglomerates. Near Beaconsfield they are estimated to be at least 2000 ft. thick. They are said to contain graptolites (*Didymograptus*) and a species of *Licrophycus* closely allied to one occurring in the Trenton Limestone. Certain limestones at Queenstown and Zeehan have yielded a species of *Tetradium* which suggests the Upper Ordovician, and a rugose coral *Favistella cerioides* has been obtained from a limestone ('Chudleigh Limestone') on the Mersey River which probably indicates a similar age. The Queen River Series¹⁵⁸ has yielded not only *Tetradium* but also *Protarea* and other corals which have Upper Ordovician affinities. In the Mersey River district Lower Ordovician beds occur which have yielded a few trilobites which are now referred to the genera *Asaphopsis*, *Tasmanocephalus*, and some *Bathyruridae*^{212, 326}.

SILURIAN

Silurian beds in Australia appear to be wholly restricted to the eastern portion of the continent, including Tasmania⁵, for none can now be found west of the eastern boundaries of South Australia, Central Australia, and North Australia¹¹⁸.

In **Victoria**^{100 226 301} the Silurian beds occupy the central portion of the main mountain system north and east of Melbourne, and have a general strike to the N.N.W. or N.W. They are separated in places by an unconformity from the Ordovician. Two divisions are recognised—a lower or '*Melbournian Series*' consisting mainly of sandstones, quartzites, and shales, with a thickness of 10,000 ft., and an upper, the '*Yeringian*' with the '*Tanjilian*' which

includes limestones; but limestones are much rarer here than on the same horizons in New South Wales, and they only occur in ellipsoidal masses. A full review and list of the Silurian fossils of Victoria has been given by Chapman²⁹⁵.

The lower division has yielded fossils which include species of *Chonetes*, *Camarotoechia*, *Rhynchotrema*, *NuciUa*, etc., and, as the name denotes, this division especially occurs around Melbourne. Some geologists²²⁷ would separate off a lowest member from the Melbournian under the name *Keilorian*, characterised by graptolites (*Monograptus concinnus*, *M. sedgwicki*, *M. priodon*, *M. turriculatus*, etc.), and consisting of mudstones, sandstones, and conglomerates. It is correlated with the Llandovery of Great Britain, while the Melbournian is considered to correspond with the Lower Ludlow and the Yeringian with the Upper Ludlow.

The limestones of the Yeringian contain a rich coral¹⁴⁴ fauna (*Favosites*, *Hdiolite* *Sy Columnaria*), while many trilobites¹⁴⁹ (*Phacops*, *Dahnanites*, *Proelus*, *Calymene*, *Lichas*, *Homalonotus*) and brachiopods (*Spirifer*, *Pentamerus*, *Leptacena*), etc.²⁹⁵, have also been obtained from these beds which are typically developed at Lilydale. Well-known Silurian genera and species of graptolites^{101 194 215 233} (*Monograptus*, *Retiolites*, etc.) have been found in places (e.g. near Keilor and Melbourne).

The highest beds, known as the *Tanjilian*^{58 159}, comprise the grey shales and mudstones of Tanjil, Starvation Creek, and Mount Matlock; these beds have a strong Devonian element in their fauna. In the Walhalla Basin the black and yellow mudstones and shales contain graptolites and also remains of the earliest-known vascular land-plants (*Homistella* and *Thuraophyton*). These beds belong to the upper part of the Melbournian¹¹⁸, and have been here termed the Walhalla Series³²⁰ by Lang and Cookson^{320 320a 320b}. Chapman¹⁶⁰, however, would put them in the Lower Devonian, though it is stated that a strong unconformity separates the Silurian from the Devonian in Victoria. It is possible that some of the igneous rocks of the Snowy River district, described below as Devonian, may be of Silurian age.

In Tasmania²⁵ the Silurian beds are folded into synclinal troughs in the Ordovician, and are known as the Gordon River Group. The beds are often very fossiliferous, and consist of slates, limestones, and sandstones full of brachiopods, as at Zeehan, Heazlewood, and the Queen River. The brachiopods comprise species of *Pentamerus*, *Orthis*, *Rhynchonella*, etc., and in the limestones at Zeehan are found the trilobites *Phacops*, *Cromus*, and *Illænus*³⁷.

The Gordon River Group²⁶ consists of quartzose sandstones, conglomerates, limestones, slates, and grits, and is developed at various places in western Tasmania. The limestones largely consist of corals (*Favosites*, *Halysites*, etc.), and amongst the mollusca the genera *Orthoceras*, *Lituites*, *Cyrtodonta*, and *Raphistoma*, are also represented. The sandstones frequently show ripple marks. The limestone rests with more or less of an unconformity on the Cambrian rocks, and is seen to succeed the Upper Cambrian (*Dikellocephalus* beds) at Railton³⁷.

In the Eldon Valley clay-slates and mudstones with *Calymene* and brachiopods are found, and beds of this age are well developed near the Mount Lyell mine, and contain *Homalonotus*.

The most conspicuous member, however, of the Silurian sequence in Tasmania is known as the *West Coast Conglomerate* which, with its interstratified quartzites, is about 2000 ft. thick and contains blocks up to nearly 3 ft. in diameter. It forms many of the high peaks in the mountainous districts of the island, and marks an ancient shore-line to the east.

Hew South Wales¹².—The Silurian rocks are a most important geological

element in the foundation of New South Wales. They consist principally of sandstones, shales, and quartzites, together with great masses of very fossiliferous limestone, and have been thrown into sharp folds striking nearly due north and south. The folding has been accompanied by great igneous intrusions, mainly of a granitic character, which have caused much contact metamorphism, but contemporaneous lavas and tuffs are also of frequent occurrence. The Silurian beds are chiefly found on the west side of the Dividing Range in the south-east part of the State, especially about the sources of the Murray, Murrumbidgee, and Lachlan Rivers. A second extensive area stretches north-west from the western slope of the central tableland past Cobar and Nymagee to the Daily River.

The typical development of these beds is near Yass^{270 299} and Bowning²⁷⁰, where they are over 3000 ft. thick, and consist of sandstones, grits, conglomerates, clay-shales, and limestones, with contemporaneous lava-flows of dacite and tuffs. The beds near Yass hardly show any cleavage or alteration, and contain some immense lenticular beds of limestone which are often very full of fossils comprising many European species of corals and brachiopods and a large number of local species of trilobites¹⁴⁹ (*Cyphaspis*, *Encrinurus*, *Proetus*, *Phacops*, *Acidaspis*, *Cheirurus*, *Calymene*, *Bronteus*, etc.¹⁴⁹). The limestones are largely composed of corals^{155 178} (e.g. *Mucophyllum* and *Halysites*). The uppermost beds (Hume beds) contain monograptid graptolites, the trilobite *Dahnianites meridiawus*, and brachiopods.

The Silurian limestones are famous for their magnificent caves, which have been formed by the solution of the rock by underground streams. The Jenolan caves³⁴³ to the west of the Blue Mountains are the best known. The Cave Limestone contains the well-known British species of brachiopod *Pentamerus knighti* of the Aymestry Limestone. It is in the Jenolan district that radiolarian cherts are found in the series overlying the limestones and reach a great thickness; thick beds of rhyolite and tuff are associated with them. But this series of radiolarian cherts and volcanic rocks is regarded by some¹¹⁸ as of Lower Devonian age. At the close of the Silurian there was an invasion of the sea in Victoria, resulting in a widespread unconformity.

In the Orange-Molong district the slates and limestones (the latter of which have a great development and contain many corals) attain a thickness of at least 5000 ft. Some rhyolitic lavas and tuffs are here also associated with them.

In the Bathurst district intrusive granite has altered the limestone in places into crystalline marbles, and the clay stones into schists of various kinds.

There are important gold and copper-ore deposits in the Silurian of New South Wales (see pp. 605-606, 611).

In **Queensland** our knowledge of the Silurian is extremely scanty¹. With the exception of the limestones of Chillagoe³²⁹, in which *Halysites*, *Heliolites*¹⁵⁵, and other corals have been found, no beds have so far been proved to be of Silurian age, but it is probable that there is a large area in the western part of the State and that a belt of Silurian beds extends north-west from south of Boulia. The slates and limestones of Cloncurry, containing *Actinoceras*, etc., may also be of Silurian age. The *Neranleigh Series* of the so-called 'Brisbane Schists'¹²¹¹ contains some doubtful eurypterid and algal remains¹⁹⁶, and may be partly of Silurian age²⁶².

In **South Australia** the presence of Silurian beds does not seem to be established.

In **Western Australia**^{26 278} a belt of quartzites, grits, and conglomerates' with some sandstones and purple slates, occurs in the Kimberley district, striking from north-west to south-east, and there are some other beds in the

Stirling district in the south of the State which have been attributed to the Silurian, though there seems to be no definite proof that they belong to it.

DEVONIAN

The Devonian system is found developed in Victoria, New South Wales, Queensland, and the Kimberley district of West Australia. The period was marked by great volcanic activity. The system has both a marine and a fresh-water or estuarine facies⁸¹. The crescentic arrangement of the outcrops from the north-western to the south-eastern border of the continent suggests the limits of the Devonian seas, for there is a complete absence of beds of this age from the inner side of this curve⁷¹. There is considerable diversity of opinion as to the position of certain plant-bearing beds which occur at the top of the system, some geologists putting them with the Devonian, and others with the Carboniferous, but here they are grouped with the Devonian, for David¹¹⁸ states that the commonest fossil in them, *Lepidodendron australe*, is the most characteristic of the Devonian plants of Australia, though he admits that the species also occurs in undoubted Carboniferous beds in Queensland.

The Devonian beds of **Victoria**^{31 226} are developed in eastern Gippsland and Croajingolong, and lower, middle, and upper divisions of the system have been recognised. Igneous rocks of volcanic, hypabyssal, and plutonic types have an immense development²²⁸.

The Lower Devonian is usually considered to be represented by the 'Snowy River Porphyries'³⁰¹ of the Snowy River district, which constitute a belt in north-east Victoria, running up from the mouth of the Snowy River on the coast into New South Wales. The group consists of a series of rhyolites and quartz-porphyrries, volcanic ashes, and agglomerates with masses of granite-porphry, etc., representing the stumps and products of a chain of volcanoes trending nearly north and south, probably situated along a line of fracture. Their aggregate thickness is 2000 ft. or more. The dacites and quartz-porphyrries of central Victoria, which were extruded from sporadic centres, such as Mount Macedon²⁶⁸ and the Dandenong Ranges, belong to the same series, and probably the alkali-trachytes near Mount Leinster in Benambra may also be placed here.

The numerous masses of granite and granodiorite²⁶⁸ in the goldfields, which are younger than the Silurian but older than the Upper Palæozoic, may also be attributed to this period of igneous activity, and so may the dykes of aplite granite, diorite-porphry, etc., which are frequently associated with the auriferous quartz-veins traversing the Ordovician and Silurian rocks. The dacite²⁶⁸ of Mount Macedon is of earlier intrusion than the granodiorite. The Mount William, Mount Wills, Granya, and other goldfields are in granodiorite or granite, and other mineral ores occur in connection with the igneous intrusions of this period. The many masses of alkali-granites, such as those of Mount Buffalo, Cape Woolamai, and Gabo Island, are probably of the same general date, and are, at any rate, mostly pre-Carboniferous.

The Middle Devonian was marked by a marine transgression; the sea occupied gulfs in the eastern part of the State, and the **thick** limestones of Buchan and Bindi were deposited in them. The lower part of the 'Buchan Series' consists of angular breccias, calcareous tuffs, lava-flows, volcanic muds, and thin-bedded limestones, 700-1000 ft. thick. Probably contemporaneously with these were deposited the slates, shales, sandstones, thin limestones, and quartzites farther west on the Wentworth and Mitchell Rivers, extending south-west beyond Cobannah, **and known as the Tabberabbera Shales and Cobannah Quartzites**. Species of *Spirifer* (*Sp. lævicosta*), *Chonetes*, *Phragmocer*, *Favosites*, *Campophytum*, *Receptaculites*, **and a large number of fish**

(including *Asterolepis*) have been collected from these beds, the corals¹⁴⁵ coming particularly from the limestones. In the Upper Devonian beds of the Acheron Valley other typical genera of fish, such as *Dipterus*, *Holonema*, and *Bothriolepis*, have been found in lacustrine deposits.

Amongst the Victorian beds of disputed Upper Devonian or Carboniferous age there is a series of sandstones, conglomerates, mudstones, and shales, with interbedded porphyries and melaphyres, which occur between the Macalister and Wonnangatta Rivers. Some geologists refer these beds to the Carboniferous, for they are not faulted or altered to the same extent as the undisputed Devonian, and lie horizontal or only gently inclined. On Iguana Creek on the Lower Mitchell River there are fresh-water sandstones which yield the characteristic Upper Devonian plant *Lepidodendron australe*, together with *Cordaites*, *Sphenopteris* and *Archceopteris* and the fishes¹⁹⁵ *Bothriolepis* and *Dipterus*; the beds rest unconformably on the Middle Devonian.

As well as these fossiliferous Upper Devonian rocks there are many volcanic rocks of this age, chiefly in eastern Victoria, including many different lithological types, and the lavas in the Marys ville Complex²²⁸ reach a thickness of at least 5000 ft., chiefly being of an acid or acid-intermediate nature.

At the close of the Devonian there were important intrusions of plutonic rocks ranging from grano-diorite to peridotite forming batholiths and dykes, with which are connected auriferous veins and contact-deposits of other minerals.

In New South Wales^{121 168 169 209 210 270} the Devonian mostly occurs in small isolated outcrops. It seems to be of two different types, the relation of which to one another is unknown, as they do not occur in the same district. But they are both unconformable to the Silurian, though some beds, from their peculiar faunistic characters, are still often described as Devono-Silurian. A general review of the palaeontology of the Devonian in New South Wales with full bibliography up to 1922 has been given by Benson⁸¹.

The Devonian beds are mainly found in the western part of the State, where they form series of ranges rising above the western plains. Most of the exposures are of no great size, but some extensive areas occur, as in the Mount Lambie-Capertee district on the western edge of the Blue Mountains³⁴⁸.

The New South Wales Devonian is provisionally divided by Sussmilch¹² into a Lower (or *Murrumbidgeean*) and an Upper (or *Lambian*) Series, the equivalents of the Middle Devonian of Victoria being included in the former. The equivalents of the Snowy River Porphyries of Victoria are found on the Murrumbidgee River, and the lower part of them at Yalwal, which succeeds the Silurian, consists of felsitic and basic lavas and tuffs. The Murrumbidgee beds, which, according to Sussmilch's classification, form a single Lower Group, include these volcanic beds (5000 ft. thick) and the overlying limestones with interbedded slates and tuffs (5000 ft. thick), which are equivalent to the Buchan and Bindi Limestones of Victoria⁸ (attributed to the Middle Devonian), and also an upper series of dark-blue shales with interbedded tuffs 7000 ft. thick. A characteristic fossil in the Lower Devonian limestones of the Murrumbidgee is the genus *Receptaculites*. The enormous development of volcanic material is noteworthy, for it reaches a thickness of 8000 ft. The chief lavas are soda-rhyolites and keratophyres, accompanied by tuffs, agglomerates, and breccias. The limestones of Coodra Vale containing coccostean fish¹⁹⁵ and the Yass²⁹⁹ beds containing *Spirifer yassensis*, etc., are probably also referable to this series.

The Radiolarian rocks (Woolomin Series), which near Tamworth^{39 249} attain a thickness of over 9000 ft. and consist of siliceous limestones, coral-limestones, clay stones, black cherts, red and green jaspers, spilite lavas, and submarine tuffs, constitute another type of Devonian rocks referred to

this Lower group. The radiolaria are estimated to amount to the number of one million in a cubic inch of the black chert. The coral^{147 148 157 270} limestones amongst these radiolarian rocks contain a rich Middle Devonian marine fauna³⁴¹ like that of the equivalent beds in Queensland. The corals from the Tamworth district¹⁴⁷ appear to represent several horizons of Lower, Middle, and Upper Devonian age; others from the Wellington district¹⁴⁸ suggest Lower Devonian age. Those from the Murrumbidgee area¹⁶⁷ are of Lower Middle Devonian age. It has been proposed that a classification of the Australian Palaeozoic can be founded on this important group of organisms. The typical plant *Lepidodendron australe* occurs associated in the shales with the radiolaria as well as in the tuffs overlying the limestone. In the Barraba and Bingara districts³⁵, north of Tamworth, a series of agglomerates and radiolarian rocks consisting of red jaspers and claystones contain *Lepidodendron australe*, and seem to follow on the Tamworth Series without any apparent physical break.

The Upper Group, or *Lambian* of Siissmilch¹², is developed typically in the Mount Lambie district along the western edge of the tableland of the Blue Mountains³⁴³. The series consists of quartzites, claystones, sandstones, reddish slates, and conglomerates, in all not less than 2500 ft. thick, and contains on some horizons a marine fauna, amongst which *Spirifer disjunctv*' and *Rhynchonella pleurodon* are especially abundant. The sandstones are often known as the 'Brachiopod Sandstones' from the predominance of these fossils⁸¹. At Capertee, north-east of Mount Lambie, a coral^{147 148 157} limestone is interbedded in the series. Many of the fossils from Mount Lambie, which were described by de Koninck¹⁷, include European species of *Spirifer*, *Atrypa*, *Orthis*, *Rhynchonella*, *Goniatites*, etc.³¹⁰. The red sandstones of Molong-Canobolas containing brachiopods, and the fish-bearing beds of the Parkes-Forbes district are also referred to the Upper Devonian. West of the Blue Mountains the marine quartzites containing *Spirifer disjunctus* and *Rhynchonella (Camarotcechia) duni* pass up into red shales and sandstones in which occurs *Lepidodendron australe*. At Wilcannia, where the Upper Devonian beds contain veins of opal²⁴⁴, the peculiar trilobite *Lichas wilcanniae*^{150 310} is found.

In the south-eastern district there is a series of fresh-water plant-bearing beds of Upper Devonian or Lower Carboniferous age, as there is in Victoria; these are the oldest fresh-water deposits in New South Wales. In the county of Auckland they have a thickness of nearly 1200 ft., and consist of shales containing *Pecopteris*, *Sphenopteris*, *Archæopteris*, *Cordaite*, and *Lepidodendron australe*.

Many contemporaneous lava-flows (rhyolites and basalts) with their tuffs are associated with the Upper Devonian in the Yalwal goldfield, where certain belts of the Devonian strata are impregnated with gold.

The folding movements which took place at the close of the Devonian period in New South Wales, and constitute the so-called Kanimbla epoch¹², were accompanied by the intrusion of great bosses and batholiths of igneous rocks, mostly granites and tonalites. The granites⁹⁶ of the southern tableland belong to this group. This was one of the great mountain-making epochs in New South Wales and along the whole eastern portion of the Australian continent.

In Queensland^{227 262} Lower Devonian beds are known at Mount Etna, near Rockhampton, where limestones have yielded a rugose coral fauna, including species of *Acanthophyllum*, *Phillipmstrea*, *Radiophyllum*, etc.¹⁵¹. Lower Middle Devonian corals from the Clermont district have also been described by O. A. Jones¹⁸² and D. Hill¹⁶⁸, and from the Silverwood area¹⁴. The radiolarian cherts in the Silverwood area²¹³ are probably on the same horizon as

the Tamworth cherts of New South Wales. The radiolarian jaspers²⁶⁰ and phyllites of the manganiferous *Fernvale Schists* at the top of the Brisbane Schists are referred to the Lower Devonian²¹¹. The Middle Devonian is largely developed, and extends from Pentland to Gilberton for 60 miles, with a width of 30 miles. It is well known in the Burdekin Valley, from which the formation receives its local name. This *Burdekin Formation*³²⁹ consists chiefly of limestones, one of which contains *Stringocephalus*, with some conglomerates, white sandstones, and red and green shales, the limestones having a total thickness of about 7000 ft. These limestones are chiefly composed of corals (*Heliolites*¹⁵⁵, *Favosites*¹⁵², *Calceola*, etc.) and stromatoporoids. The lower part of the Burdekin Formation consists of unfossiliferous slates, grits, and conglomerates, and is referred¹¹⁸ to the Lower Devonian. Bryan²⁰⁸ believes that the Brisbane Schists are of this age. In the Fanning limestone of the Burdekin basin we see representatives of the Rhynie flora of Aberdeen, the plant *Schizopodium*³⁴⁶ being present, but the middle portion is characterised by species of *Gyroceras* and *Phragmoceras*. Upper Devonian beds containing plant-remains like those of Mount Lambie are found in some places (e.g. at Mount Wyatt), and the Berserker Series of Rockhampton, consisting of andesitic tuffs with large blocks of *Stromatopora*, is also referred to the Upper Devonian¹¹⁸.

In **South Australia**, **Central Australia**, and the **Northern Territory** it is doubtful if any Devonian beds exist.

In **Western Australia**^{139 165 278 316} Devonian beds are well developed in the Kimberley Division^{146 165} over an area of 2000 sq. miles, and reach a thickness of over 10,000 ft. They consist of hard grits, conglomerates, limestones, and shales, and contain a marine fauna having a European facies, the fossils including the European Upper Devonian species *Atrypa aspera*, *Rhynchonella cuboides*, and *Spirifer verneuili*, together with corals and stromatoporoids⁵⁴.
135 139 146 155 The Upper Devonian includes a limestone known as the Productella Limestone, containing a species stated¹⁸⁹ to resemble closely the European species *Productella productoides* (Murch.), and the series also comprises a succession of zones characterised by goniatites^{135 139 160}, including species of *Sporadoceras*, *Dimeroceras*, and *Pseudoclymenia*. Interbedded with these deposits are contemporaneous dolerites, volcanic breccias, and tuffs. The lava-flows cover hundreds of square miles. The whole of the Devonian rocks have a strike from north-east to south-west, and are much folded, whereas the neighbouring Carboniferous strata are almost horizontal.

In **Tasmania** Devonian rocks are stated by Andrews³ to be absent, but some geologists attribute the *Fingal Slates*, which contain the lamellibranch *Arch-anodon* (*Anodonta*) *jukesi*, to this period. The massive quartzites and coarse conglomerates of the Dial Range and Table Cape, which contain rolled pebbles of fossiliferous Silurian beds, may also be of Devonian age.

A great series of granitic and other intrusions characterised the Devonian period in Tasmania, as on the mainland.

These granites⁸⁷ and other acid intrusions pierce all the rocks earlier than the Permo-Carboniferous. The Upper Palæozoic granite is distinguished from the older granite by its uncrushed condition, and it occurs in a meridional line down the east coast from Flinder's Island to Maria Island, and at Ben Lomond, Lyell, Mount Cameron, the Hampshire Hills, the Meredith Range, and Mount Heemskirk. Many dykes also of quartz-porphry or granite-porphry and mineral veins date from this period (e.g. Mount Bischoff, with its deposits of tin-ore). Serpentine intrusions containing nickel and osmiridium are characteristic rocks, and are generally found as peripheral modifications

of ultrabasic rocks surrounding the granite masses on the west coast, but they are of earlier date than the acid intrusions, since the latter pierce and alter them³⁷.

Igneous rocks.—The igneous activity which prevailed in all eastern Australia during Devonian times, as above described in Victoria, was marked by the extrusion of many types of acid and basic lavas accompanied by tuffs and agglomerates, and was exhibited at the end of the period by plutonic intrusions on a large scale, chiefly of granodiorites and granites; sills of porphyrites and quartz felsites also were intruded, and in a few cases basic rocks (norites) occur¹¹⁸. The chief type of intrusive rock is granodiorite, but alkali-granites are also found. The date of all these intrusions varies somewhat, and some belong even to the Carboniferous.

Most of the granites^{96 118} of New South Wales may be of late Devonian or Lower Carboniferous age (Kanimbla intrusive epoch). The ore-deposits of gold, copper, silver-lead, tin, etc., round the batholiths in New South Wales and the gold of Bendigo, Ballarat, and other localities in Victoria, are related to these intrusions.

In Queensland³⁴² volcanic activity was specially developed in the southern parts of the province, and lavas of many petrological types were poured out.

CARBONIFEROUS^{137 175 273}

The relations of the Devonian to the Carboniferous are not of a simple or uniform character throughout eastern Australia. Thus in north-eastern New South Wales the Carboniferous follows on the Devonian conformably, and the beds of both systems are strongly folded together, whereas in western New South Wales the Devonian is merely thrown into gentle rolls and folds with only local sharper plications. According to Sussmilch¹², the close of the Devonian in New South Wales was marked by great orogenic movements, whereas in Victoria there were earlier movements which took place during the deposition of the Devonian and are indicated by the unconformity between the Middle and Upper Series. In Western Australia the Devonian strata were folded before the deposition of the Carboniferous. The whole of Tasmania, and most of Australia west of long. 142° E., appears to have been a land surface, according to David¹¹⁸, during Lower Carboniferous and the earlier part of Upper Carboniferous times. David⁶ states that no general unconformity has so far been traced between the Devonian and Carboniferous rocks throughout Australia, and apparently the above-mentioned unconformities are of a local and restricted nature. The dispute as to the Upper Devonian or Lower Carboniferous age of certain plant-bearing beds in eastern Australia, to which reference has been made, is not yet settled, and has given rise to much confusion in describing the dates of the earth-movements, and in correlating the beds. On the other hand, the sharp distinction between the floras of the Carboniferous and Permian (=Permo-Carboniferous) which has been emphasised by Walkom²⁸⁵, is most noticeable.

In Victoria²²⁶ the 'Avon River Sandstones' are referred by some geologists to the Lower Carboniferous, but by others¹¹⁸ to the Upper Devonian. These sandstones extend in a band trending northwards across central Gippsland to Mansfield, where the 'Mansfield beds' set in. The latter consist of a thick series of coarse and fine sandstones, conglomerates, mudstones, and shales, with occasionally impure limestones, and they contain Lower Carboniferous fish (*Acanthodes*, *Ctenodus*, *Elonichthys*, etc.) in association with the plant *Lepidodendron mansfieldense*.

The ' *Grampian Sandstones* ' which compose the Grampians and two parallel ranges of the horst type in the western district, and are not folded and only rarely tilted at steep angles, are likewise referred to the Lower Carboniferous. They yield *Lingula* and fish-remains similar to those in the Mansfield beds.

In **New South Wales**^{12188 218 261} the earth-movements which closed the Devonian converted most of the State into dry land, but a considerable part of the north-eastern districts was covered by the sea during some part of the Carboniferous period, and even in the south and west some marine as well as fresh-water beds were also deposited. The marine Lower Carboniferous is known as the *Burindi Series*^{118 259 273}, and includes oolitic limestones with a Viséan fauna¹⁶⁴, including many European species^{87 163 164}. The genera *Syringoihyris* and *Phillipsia*⁶, are specially conspicuous.

The Upper Carboniferous, or *Kuttung Series*^{116 218} 25 9, into which the Burindi Series passes up without any angular unconformity, includes the *Bhacopteris Stage*^{12 177}, in which there is a predominance of that genus of plants. The Kuttung formation is fresh-water and terrestrial in origin. There are also beds of inferior coal in the series, and contemporaneous lavas and tuffs, but the most interesting are the conglomerates, varved shales^{128 254}, and tillites of glacial origin at the top of the series¹¹⁶. The occurrence of these glacial beds at a lower horizon than the Talchir beds of India and the Dwyka beds of South Africa is remarkable, and indicates an earlier advent of cold conditions in Australia. Some of the tuffs containing the typical genus *Rhacopteris* are interstratified with the glacial beds. It must be observed¹⁰⁸¹³⁷ that the glacial deposits of the Kuttung Series are lithologically different from the later glacial beds of the Permo-Carboniferous¹⁶⁷, and the materials composing them were derived from other sources. The Carboniferous varves at Paterson, New South Wales, have been measured by Caldenius²⁵⁴. There are two glacial horizons in the Upper Kuttung¹³⁶ of the Werrie Basin which are separated by an interglacial stage of tuffaceous rocks. The glacial beds are tillites with striated boulders. Carey¹³⁶ applies to this Middle Carboniferous glacial series the name *Kullatine Series*. A review of the whole Carboniferous stratigraphy in New South Wales has been given recently by Carey and Browne¹⁷⁵.

Vulcanicity is a marked feature of this Upper Series, and the volcanic rocks include rhyolites, hypersthene-andesites, and tuffs with interstratified deposits of titaniferous magnetite. Immense sills of quartz-porphyry also intersect these beds. In the Hunter River District²³⁹ the glacial stage follows on the volcanic stage, and comprises fluvio-glacial conglomerates and varved shales succeeded by three beds of tillite with tuffs and a thick bed of varved shales intercalated, the whole stage measuring over 1800 ft. in thickness.

The dark felspar-porphyrries (*e.g.* around Tenterfield) and the ' Blue Granite ' are probably Carboniferous intrusions, and at the close of the Devonian or Carboniferous the great masses of serpentine³⁵ were also intruded, of which the belt from the Bingara to Port Macquarie, 200 miles long, is an example. Probably their intrusion accompanied the folding of the Carboniferous.

In **Queensland**²⁴,^{98 262} Carboniferous beds occupy wide areas from the New South Wales border to north of Cooktown. The ' *Star Formation* '⁸²⁹, which is now considered to be older than the Gympie Series (referred to the Permo-Carboniferous), has its type district situated at the junction of the Great and Little Star Rivers, and here it consists of 1300 ft. of conglomerates, sandstones, shales, and thin limestones. There has been considerable difference of opinion³²⁹ as to the age of the Star Formation. It was first referred to the Upper Devonian, then to the Carboniferous, or even to the Permo-Carboni-

ferous, but later partly to the Devonian and partly to the Carboniferous¹¹⁸. Some of the beds contain plant-remains, including *Lepidodendron*, *Cakmites*, and *Cordaite*s. The marine fossils in the limestones include *Phillipsia*, *Orthis*, *Choneies*, and *Rhyndwnella*, and many fish-remains. There are also contemporaneous amygdaloidal dolerites and porphyrites interbedded in places with the sedimentary rocks, and the porphyrites often contain large masses of native copper. The Rockhampton³²⁹, Drummond, and Herberton beds have the same general characters and a typical Carboniferous fauna and flora. The *Lower Rockhampton Series* follows conformably on the Upper Devonian *Lepidodendron-australe* beds, and consists of a series of black cherts and volcanic tuffs, in all about 5000 ft. thick. The cherts contain Tournaisian cephalopods (*Proiocanites*, *Pseudarieites*). The *Upper Rockhampton Series* contains a Visean fauna as in the Burindi Series of New South Wales, and is composed of mudstones, grits, and conglomerates, with oolitic limestone containing reef-building corals (*Aphrophyllum*). There is a specially rich coral fauna at Riverleigh and Lion Creek¹⁴⁴ which may be slightly younger than Visean. At Hilldale, north of Maitland, a *Syringothyris* zone overlying shales with abundant crinoids is remarkable. There is some evidence of the occurrence of the Kuttung Series in Queensland⁹⁸, beds with *Aneimies* occurring in the Drummond Range and near Herberton resting on a basal conglomerate.

Western Australia.—Massive limestones¹¹⁸, richly fossiliferous, occur in the Kimberley area³³¹, containing *Lithostrotion affina*, *Schdlwienella crenistria*, *Schizophoria resupinata*, *Spirifer striatus*, etc. They are overlain by shales and sandstones.

In Tasmania²⁵ no Carboniferous beds have been proved to exist. But by some geologists it is believed that the great mass of greenstones¹³⁰ which form the central plateau of the Lake Country and the crests of Ben Lomond, the Eldon Range, and other heights was poured out at the close of the Devonian or early in the Carboniferous period; for the Permo-Carboniferous Formation rests almost horizontally and quite unaltered upon them²⁵.

Igneous Rocks.—The upper portion of the Carboniferous is characterised in Australia by a great outpouring of volcanic material¹¹⁸. The lavas and tuffs are mostly of an acid composition, and include rhyolites and keratophyres⁹⁵, but with them occur hypersthene- and hornblende-andesites. David¹¹⁸ considered that the only intrusive rocks of Carboniferous age are the serpentines and allied basic rocks of the Great Serpentine Belt of New South Wales⁸⁷, but according to others some of the granite batholiths⁹⁶ and quartz-porphyrries also belong to the close of the period.

Tectonic **Movements**.—The last great folding-movements^{175 206 209} on the Australian continent took place at the close of the Carboniferous, for the beds of this system are mostly closely folded, whereas the Permo-Carboniferous strata rest unconformably on them either horizontally or only gently and broadly undulated. In some places, however, the unconformity is scarcely evident. According to Carey and Browne¹⁷⁵ five earth-movements have affected the Carboniferous rocks during or after their deposition in New South Wales and Queensland.

PERMIAN (=PERMO-CARBONIFEROUS)^{137 305}

The Permian or 'Permo-Carboniferous' beds are very widely spread in Australia, and consist partly of marine and partly of fresh-water deposits, while

the evidence of glacial action near their base makes them of peculiar interest. The presence of coal-seams renders them of great economic value, and the close resemblance of the whole series in its physical and palæontological characters to the Lower Gondwanas of India⁸⁸ and to the Lower and Middle Karroo of South Africa²⁴¹ gives to the whole formation great geological importance. The eastern Australian fauna of these beds is remarkable for the development of many exclusively Australian types, whereas the western is more allied to that of the equivalent marine beds in India, and has some Carboniferous species intermingled with it. The *Glossopteris* flora is characteristic of the series, as in India and Africa, and the presence of similar glacial boulder-beds at the base is likewise especially noteworthy^{20 32 166}. The same type of fresh-water sedimentation and flora is maintained into Jurassic times just as in India and South Africa.

There exists a wide difference of opinion as to the horizon at which the division between the Permian and Carboniferous should be drawn in Australia, David^{116 118 137 218} and Schuchert^{150 161} holding different views, and differently correlating the beds. Kaggatt and Fletcher¹⁰⁶ have further discussed the question, and so has Du Toit in connection with the glacial beds in South America and South Africa¹⁶². Walkom³⁰⁵ had previously suggested the Lower limits of the Permian System in Australia. As mentioned above, the incidence of glacial conditions appears at any rate to have begun earlier²¹⁸ in Australia than in India or South Africa, and the glacial and interglacial periods or phases had more frequent recurrence. Floating ice reached also farther from the land, so that marine fossils were included in the deposits, and glacial lakes with varved clays^{137 254} were more common. It is remarkable that the ice seems to have moved polewards, though the ice-sheets originated at a latitude so far south of the equator.

Structurally, the Permian beds in Australia lie either horizontal or in broad open folds, whereas the Carboniferous beds are mostly disposed in fairly close folds^{6 175}. There is, however, only local evidence of the existence of an unconformity between them, and it is nowhere so strong as that between the Carboniferous and Permian in England. But the palæontological break is usually complete, for no Carboniferous species in eastern Australia range up into the Permian, according to Dun, though, as above stated, in Western Australia this is not the case, and it depends where the division between the Carboniferous and Permian is drawn, for, according to David^{116 118}, part of the Lower Marine Series, containing the early *Glossopteris-Gangamopteris* flora, should be correlated with the Upper Carboniferous (Uralian), whereas Schuchert^{150 161} puts these beds in the early Middle Permian. Walkom⁸⁰⁵, Raggatt, and Fletcher¹⁰⁶ definitely refer them all to the Permian, and their view is here adopted.

In New South Wales^{12 106 116 118 157 177 218 259} there is the fullest development of the Permian, and the beds have a maximum thickness of 17,000 ft., forming David's^{116 118 137 305} *Kamilaroi System*. The Permian Coal-Measures alone in this State occupy an area of over 16,000 sq. miles, and the main coal-basin extends for nearly 200 miles along the eastern coast-line, i.e. from near Port Stephens in the north to Ulladulla in the south, the deepest part (2800 ft.) of the basin being near Sydney. The total area occupied by the Permian rocks is 24,000-28,000 sq. miles, and they extend inwards from the coast over a large roughly triangular region.

Where the Permian here comes in contact with the Carboniferous there is frequently a considerable overlap of the newer upon the older rocks, but, according to David^{116 218}, there is no angular unconformity, though there is a marked break both palæontologically and lithologically. The system comprises marine, fresh-water, and glacial beds, and is now subdivided as follows by

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a thickness in the Hunter River district of 150-250 ft., and contain two important coal-seams and a rich flora. The beds are mostly sandstones, conglomerates, and shales¹¹⁷. In some places patches of kerosene oil-shales occur. The *Glossopteris* flora is found in this series, and the genus *Gangamopteris* is specially abundant. In addition to the two typical genera, *Glossopteris* and *Gangamopteris*, the plants *Phyllothea*, *Noeggerathiopsis*, and *Dadoxylon* occur in these beds.

The Greta Coal-Measures crop out as a narrow belt of rocks, and near Maitland dip under the Middle or Tomago beds and Upper Coal-Measures. They have been traced across the Queensland border, and in the New England table-land are 400 ft. thick. In the Illawarra coalfield volcanic lavas and tuffs are interbedded, and everywhere igneous rocks have invaded the series.

(3) The *Upper Marine beds* extend over a wider area than any of the other divisions of the Permian, and crop out all round the edges of the main coal-basin. In the Hunter River²⁶⁹ district they reach a maximum thickness of 6000 ft. In the western coalfield (Lithgow-Capertee district) the Lower Marine beds and Lower Coal-Measures are absent, and the Upper Marine beds rest unconformably on highly-tilted Lower Palæozoic beds, having conglomerates (sometimes auriferous) at the base, containing large boulders of granite and other rocks which are often striated. But erratics occur almost continuously through the Muree Stage and above it. At Branxton a true glacial bed occurs in the middle of the series, and a well-marked group of *Fenestella* shales. There are shales, grits, and sandstones in the succession with crinoidal beds, the latter containing the characteristic genus *Tribrachio-crinus*. A rich fauna of brachiopods and mollusca is known from them, which is practically identical with that in the Lower Marine beds. The only Permian ammonoid, *Adrianites* (*Neocrinites*) *meridionalis* Teich. and Fletch.³³⁰, from the Upper Marine Series of the Hunter Valley, has been recently described; all the other fossils referred to various genera of ammonoids are probably bellerophonitids. In some areas (e.g. the Kiama district, and in the region from the Cambewana Mountains to Port Kembla) the upper part of the series has the sedimentary beds largely replaced by great flows of submarine alkaline lavas, volcanic tuffs, and agglomerates, varying from intermediate to basic in composition, and reaching a thickness of about 1000 ft.¹²⁴. Associated with them are sills of monzonite. Some of the eruptions of this area were prolonged into Triassic times⁹⁵.

(4) The *Upper Coal-Measures*.—The *Tomago beds*, 500-3000 ft. thick, which were formerly separated off as the 'Middle Coal-Measures' or 'East Maitland beds,' are now¹⁰⁶ grouped with the Newcastle beds as a stage in the Upper Coal-Measures, for they possess the same fossil plants. The *Dempsey beds*, about 2000 ft. thick, which were also separated and consist of shales with a similar flora, are now regarded also as only a facies of the Tomago Coal-Measures. But the latter are not present in the southern (Illawarra) or western (Lithgow) coalfields, where the Newcastle beds rest directly on the Upper Marine Series. The *Newcastle Stage* is the principal coal-bearing horizon in New South Wales, and extends over nearly the same area as the Upper Marine beds, immediately succeeding them, except in parts of the Hunter River district. In the Newcastle district this group is over 1200 ft. thick. The coal-seams are numerous and crop out in the neighbourhood of Newcastle in the north, Bulli in the south, and Lithgow in the west, and extend continuously under the deeper portions of the basin. The other beds comprise sandstones, conglomerates, shales, and cherty tuffs. There is an **abundance** of fossil plants in these beds, including *Phyllothea*, *Sphenopteris* (*Sph. lobifolia*, *Sph. alata*), *Glossopteris browniana*, *Gl linearis*, *Gangamopteris*, etc., and the flora bears a close resemblance to that of the Damuda beds in

India, several of the species being identical. The fossil insects¹⁷⁶ are a noticeable element in the fauna in the chert of the Upper Coal-Measures in New South Wales and Queensland, which is largely composed of rhyolitic volcanic dust. The oil-shales²⁰⁵ in the Upper and Lower Coal-Measures occur mostly in lenticular patches and are considered to be chiefly formed by an alga, *Reinschia australis*, and by the pollen of coniferous trees.

In **Victoria**^{531 226} the glacial deposits²⁰ are extremely well developed and widely spread, and have long been known as the *Bacchus Marsh beds*^{40 41 267 279}. They form the lowest and only Upper Carboniferous beds in the State, and are found at Bacchus Marsh, Heathcote, Bendigo, Loddon Valley, South Gippsland, and in other localities. They rest on strongly-folded and denuded Ordovician beds, and on post-Ordovician granites which exhibit a surface strongly striated and grooved by ice coming from a southerly direction. The series is over 2000 ft. thick in some places, and consists of one or more boulder-beds, with bands of shale, sandstone, or conglomerate interstratified. The boulder-beds are true imstratified tills, and are composed of fine mud or dark greyish clay filled with pebbles and boulders of a great variety of rocks, chiefly granites, porphyries, gneisses, schists, cherts, jasper, quartzites, sandstones, and slates, some of which are not known *in situ* in Victoria. The boulders are generally rounded, sub-angular or faceted, polished or striated, and range in size up to masses weighing 20 or 30 tons. Very large erratics are especially characteristic of the Heathcote area. At Bacchus Marsh, where the whole thickness of the beds is estimated at only about 500 ft., there are at least nine or ten distinct boulder horizons. No contemporaneous fauna has been found in these beds, but at Bacchus Marsh they are succeeded by sandstones containing plant-remains, including several species of *Gangarnopteris*. The upper part of the Bacchus Marsh beds is Triassic, as shown by the flora²¹¹. There are no Permian beds in Victoria containing marine fossils as in New South Wales, and the boulder-beds are generally followed immediately by the Mesozoic Coal-Measures. As in South Australia the glacial beds seem to have been formed by land-ice with its main source to the south of the present continent⁷¹, and to be largely of the nature of moraines.

In **Tasmania** 25 37 68 116 127 the Carboniferous and Permian occur chiefly in the eastern half and in the centre of the island. The beds are usually horizontal or only gently inclined, and are known under the following names. In those places where the Tasmanite beds are present the Coal-Measures are absent. Their maximum thickness is estimated at about 2000 ft.

- (1) Upper Marine beds.
- (2) Tasmamite beds or Lower Coal-Measures.
- (3) Lower Marine beds.

The basal members of this sequence consist of conglomerates, grits, mudstones, limestones, and sandstones, containing boulders of granitic and gneissic rocks which indicate the action of ice. These are the *Wynyard*⁵⁰ *Glacial beds*, and are 1200 ft. in thickness. They show at least three ice-striated pavements in the tillites themselves, and underlie a marine fossiliferous series. They are correlated with the Hallett's^{71 182} Cove and Inman⁷¹ Valley Upper Carboniferous glacial beds of South Australia, and with the Bacchus Marsh beds of Victoria²⁰. In the Korkuperrimul district²⁷⁹ eleven tillites and glacial mudstones constitute nearly all the Permian, and point to many local advances and retreats of the glaciers. The Wynyard Glacial beds rest unconformably on the older Palaeozoic in the Mersey district, or on the 'older greenstones' (as near Hobart), and some of the beds contain the characteristic marine fossils of the New South Wales marine beds, including *Spirifer (Martiniopsis) darwini*,

Productus brachytherus, *Aviculopecten limæformis*, *Conularia laevigata*, *Eurydesma cordatum*, *Pachydomus globosus*, and *Fenestella*. Three zones, named respectively the *Spirifer*, *Pachydomus*, and *Fenestella* zones, have been recognised³⁷. On Maria and Bruni islands, the boulder-beds are specially well seen. There are at least three, if not four, boulder horizons, and it is thought that the intervening beds mark inter-glacial epochs. The Lower Marine beds in the Mersey Basin are usually succeeded by the Upper Marine beds, but in the coal-area of this basin a fresh-water and terrestrial series, known as the *Lower or Mersey Coal-Measures*, is intercalated and corresponds to the Greta Series of New South Wales, holding the typical species of *Glossopteris*, *Gangamopteris*, etc.⁶⁸ This series consists of shales, sandstones, and conglomerates, with coal-seams, 1-2 ft. thick, which are worked in several coalfields; the best coal occurs in the Wynyard (Preolenna) field⁵⁰. The plant-remains are those characteristic of the Permian elsewhere.

The *Tasmanite Shales*¹⁷⁴ consist of finely-laminated shales, arenaceous flags, and a bituminous yellow coal, called tasmanite, occurring in bands 3 in. to a few feet thick, and full of the spores of lycopods, which also occur in some of the shales. Characteristic marine fossils of the Marine Series (*Spirifer*, etc.) are found associated, so that the Tasmanite must be regarded as a marine deposit. Where the Tasmanite Shales occur the Lower and Upper Marine beds form a continuous series. This peculiar deposit is of commercial value as a source of oil³².

The overlying *Upper Marine Beds* contain practically the same fauna as the Lower Marine beds, and consist of fossiliferous mudstones and sandstones, with small glacial erratics. There are certain alkaline rocks comprising soda-trachytes (tinguaites and solvsbergites), accompanied by their tuffs, which are stated to be interbedded with the marine beds in the Port Cygnet and Oyster Cove districts, and associated with them are elseolite-syenites, foyaites, etc., but some of these at any rate are proved to be intrusive in the Lower Marine Series³⁷. The Mount Pelion Coal-Measures with *Glossopteris* are correlated^{116 118} with the Upper Coal-Measures of New South Wales and Queensland.

In **South Australia** the Hallett's Cove^{20 41 71 132} glacial beds, on Gulf St. Vincent, near Adelaide, are believed to be of Upper Carboniferous age, and to be an extension westwards of those in Victoria. They consist of greyish mudstones containing well striated boulders, which are chiefly composed of a porphyritic granite found *in situ* 3 miles to the north, and range up to 8 tons in weight; the beds rest on a smoothed and striated platform of Pre-Cambrian rocks²⁰. Above them are reddish clay-slates, which are overlain by Miocene limestones. Similar glacial beds occur in other localities in this province, and are sometimes covered unconformably by Cretaceous, Eocene, or Miocene deposits. One of the most remarkable occurrences is in the Inman Valley, where the glacial beds fill an old valley in Cambrian rocks^{71 91}, and reach a thickness of 1000 ft. The striations on the floor show that the ice travelled in a north-westerly direction⁷¹, and seems to have had a thickness of 1800-2000 ft. The Pertnara Conglomerate in the Macdonnell Ranges in Central Australia is supposed to be of Permian (Permo-Carboniferous) age²⁹².

At Treachery Bay, on the coast of the **Northern Territory**²⁰⁸, there are limestones forming a continuation of those in the Kimberley Division of Western Australia, and containing a similar fauna. The 'Permo-Carboniferous' beds are the latest deposits on the Pre-Cambrian plateau³³⁵ in central North Australia.

In **Queensland**^{5 24 '98 99 262} the *Lower Bowen*³²⁹ and *Gympie Series* are now referred to the Lower Permian and Upper Carboniferous, respectively, for the

fossils which they contain are found to be of these ages. The beds occur north of Brisbane, and south of Maryborough, and especially at Gympie, where they are 2000 ft. thick, and consist of greywackes, sandstones, carbonaceous shales, and conglomerates, with some impure limestones in places. Volcanic tuffs, agglomerates, and andesitic lavas also occur in the series, and numerous gold-reefs are found in it as well as other minerals {e.g. antimony, tin, cinnabar, bismuth, and cobalt}. In some parts the series has suffered extensive metamorphism, and is strongly folded and pierced by various intrusions, especially greenstones.

The Gympie Series^{24 329} has a great development in the south-east part of Queensland, and in the Rockhampton district the thick limestones contain an abundant marine fauna. A remarkable algal limestone of great thickness occurs at Gigoomgan¹⁹⁶ in the Permian and contains many other organisms besides algae. The presence of large boulders of greywacke and other rocks in some beds of shale probably points to the action of floating ice, but nothing approaching a true tillite has been found in this area. The *Lower Bowen Series* in the Springsure district^{98 99} consists of gypseous beds, sandstones, and a coral stage with *Trachypora* and *Monilipora*, all below the glacial or Dilly Stage which contains erratics. The characteristic Lower Marine fossils (*Eurydesma*, etc.) as well as *Glossopteris* occur in many of the beds.

In the Dawson River Basin we find the Lower Bowen Series represented by Marine beds at the base containing boulders, probably transported by ice, followed by volcanic rocks and sedimentary deposits, with an 11-ft. thick seam of anthracite. Further marine sediments follow, and these are succeeded by *Glossopteris* beds⁵. The Collinsville Coal-Measures are correlated with the Greta Coal-Measures of New South Wales, and between the Collinsville and Mount Devlin Coal-Measures in the Bowen River district there are rhyolites, andesites, and zeolitic basalts¹¹⁸.

The *Middle Bowen Formation*, corresponding with the Upper Marine Series of New South Wales, and 2400 ft. thick, is typically represented on the Bowen River to the north of the Dawson River basin, and consists of sandstones (full of characteristic Permian marine fossils, *Spirifer (Martiniopsis) darwini*, *Derbya senilis*, *Productus brachythcerus*, *Pachydomus globosus*, *Mæonia carinata*, etc.), shales, a few seams of coal, and conglomerates, the latter containing in places some large isolated boulders of granite and other rocks, probably of glacial origin²⁶. Plant-remains include the common species of *Glossopteris*,

The *Upper Bowen Formation* contains many coal-seams, and is mainly developed in the centre of the great basin of the Bowen coalfield, and also at Townsville and Cooktown in the northern part of the State. The series consists of grey shales and greyish-green sandstones with coal-seams; intrusive sheets of trap are also common. One of the coal-seams at Blair Athol has a thickness of 93 ft. Silicified tree-trunks are of frequent occurrence, and occasionally the conglomerates are auriferous. The marine fossils are like those of the Middle Bowen, and the plant-remains include several species of *Sphenopteris*, *Glossopteris*, and *Phyllothea*. The series is generally considered equivalent to the Tomago, Dempsey, and Newcastle beds of New South Wales. In late Permian times an epeirogenic elevation of Queensland took place without any folding²⁰⁶, and was followed after an interval of tension and block faulting, such as is seen in the Silverwood area²¹⁸, by an intrusion of important masses of stanniferous granite. Volcanic activity was also specially marked in Permian times⁸⁴² in various parts of Queensland.

In **Western Australia**^{26 33 106 108 116 118 165 166 171 278 316}, the **Upper Carboniferous** and Permian rocks cover a large area, and are best known in four regions, i.e. Kimberley^{278 331}, Gascoyne, the Irwin River, and the Collie River, where palæontological evidence is available. They are everywhere divisible

into (i) a lower or mainly limestone series, and (ii) an upper or mainly sandstone series, with some coal-seams. The fauna of the lower or limestone beds is very rich, and was previously thought to resemble that of the true Carboniferous (Mountain) Limestone of England⁶⁴, but now^{165 168 827 333 334} is regarded as more allied to that of the Productus Limestone of India. The limestone and sandstone series succeed each other conformably in the Haughton Range and in the Gascoyne region. According to Teichert³¹² the ammonoids from Kimberley, the North-West Division, and Irwin River indicate three faunas of slightly different age. The youngest horizon is that of the North-West Division (Wandagee Series) and contains species of *Propinacoceras*, *Paragastrioceras*, *Agathiceras*, *Pseudoschistoceras*³³³, and *Pseudogastrioceras*, as well as teeth of the shark *Helicoprion*. The lower horizon is the Nura Nura Limestone of Kimberley, which contains species of *Metalegoceras* and *Thalassoceras*. The oldest fauna is that of the Irwin River, containing *Metalegoceras jacksoni* on three distinct horizons above the basal tillites. The ammonoids are mostly allied to species occurring in Timor.

There is a persistent boulder-bed of probably glacial origin⁷⁴ interstratified with the Upper Carboniferous rocks in the north-west and on the Irwin River. It is called the *Lyons Conglomerate*¹¹, and marks an important geological horizon. Its fossil contents imply a marine origin, and the boulders are frequently striated and consist of granite and other rocks. The *Gascoyne Series*¹¹, which consists of limestones, shales, and sandstones, and contains some erratics, succeeds the Lyons Stage. The Irwin River beds contain a fauna closely related to that of the Productus Limestones of the Salt Range in India, and many of the species seem almost identical^{165 166 171 327}. Bryozoa are especially abundant³²⁵. This type of fauna prevails in all the marine Permian beds from the Irwin River to the Gulf of Carpentaria. Overlying these marine strata on the Irwin River are two seams of coal of probably the same period.

The Collie River coalfield covers an area of about 500 sq. miles, and the beds attain a thickness of at least 2000 ft. They consist of shales, sandstones, and grits, with coal-seams⁵⁰, which have an aggregate thickness of over 140 ft., and yield well-known Indian and Australian species of *Glossopteris*. This fragment of a much larger sheet of Permian owes its preservation to a deep trough-fault, which has dropped it down into the older granite basement. Some of the coal-measures in this field are of Lower Permian, but others of Upper Permian age.

It is probable that the *Wilkinson Range Series*^{119 120}, which comprises glacial boulder beds with striated erratics of granite, gneiss, quartzite, etc., associated with sandstones and claystones, may be of 'Permo-Carboniferous' age. The beds are horizontal and rest on granite or on Ordovician rocks.

In **Central Australia**^{85 116} the *Finke Series* of grits, shales, and tillites, underlying the Cretaceous beds, may be of Carboniferous or Permian age, or much younger.

Tectonic Movements.—The structural history of Australia as a whole during the Palaeozoic has been described by Andrews¹⁸⁷. Late Permian and epi-Permian movements²⁰⁶ took place in Queensland, as in the Bowen Basin, where the Upper Bowen Coal-Measures are in places overturned to the westward, but farther south, in New South Wales, except in the north-east and in Tasmania, the Trias and Permian are conformable¹¹⁸. Probably the Irwin River Series in Western Australia and the Permian of the Wooramel area (included in the Gascoyne Series⁸⁴¹) suffered the folding movements at the same time as Queensland. There were extensive intrusions of plutonic rocks accompanying these earth-movements, and in New South Wales and

Queensland granites and pegmatites invaded the rocks, and many ore-deposits originated with them as, for instance, on the New England plateau²⁶¹.

TRIAS-JURASSIC

In Australia there is no clearly-defined Triassic System separable from the Jurassic, a considerable uniformity of character in the organic contents prevailing through the whole sequence which is chiefly of fresh-water origin and lacustrine. All the beds therefore between the close of the Permian and the Cretaceous are here treated together. David¹¹⁸ states that lacustrine conditions persisted from Upper Permian into Triassic times, but with modified shore-lines, and that over much of eastern and central Australia great lakes existed, varying in extent during Triassic and Jurassic times.

New South Wales¹².—Though the same general physical conditions prevailed here as in the Permian, and the nature of the sedimentation was unaltered, yet the change in the flora²⁴¹ is marked, and corresponds with that which took place between the Middle and Upper Karroo of South Africa²⁴¹. The genus *Glossopteris* and its associates have disappeared, and a new assemblage of plants takes their place. We may broadly correlate these beds of eastern Australia with the Upper Gondwana Group.

In the north-eastern part of New South Wales orogenic movements elevated and folded the Carboniferous and Permian beds as far south as the Hunter River, and this folding was even more pronounced farther north in parts of Queensland. On the other hand, western and southern New South Wales were scarcely affected by these movements, so that the same beds in these parts lie almost horizontal. The sediments of Trias-Jurassic age which were deposited in the north after these movements took place are characterised by massive conglomerates and coal-seams, whereas tuffs and sandstones without heavy conglomerates or coal-seams are typical of the southern and western areas. The southern or Hawkesbury area seems to have been separated from the northern basin of deposition by a land-barrier during part of the period, and the deposits which were laid down in the southern area succeeded the Permian without any apparent stratigraphical unconformity. These southern beds are known as the *Hawkesbury Series*, and crop out along the coast from the Shoalhaven River nearly to Newcastle. Inland they extend westwards to Lithgow, and cover most of the tableland of the Blue Mountains.

Throughout this whole series, which is of fresh-water, lacustrine, or estuarine origin, the plant *Thinnfeldia odontopteroides* is characteristic.

The series is usually divided into the following stages :—

- (3) Wianamatta Stage.
- (2) Hawkesbury Sandstone Stage.
- (1) Narrabeen Stage.

(1) The *Narrabeen beds* are largely tuffaceous and consist of red and chocolate-coloured shales, cupriferous and *Estheria* shales, sandstones, and a few conglomerates. The tuffs are basic in character. The total thickness amounts to about 1800 ft. near Sydney, but the beds thin westwards. Fossil plants are abundant.

(2) The *Hawkesbury Sandstone Stage* directly succeeds these beds near Sydney, and consists of massive thick current-bedded sandstones and grits, with a maximum thickness of about 1100 ft. It frequently contains gold disseminated through the rock, but to a very small amount. A prismatic structure has frequently been induced in the sandstones by intrusive basalt. The beds contain few fossils, but some remains of ganoid fishes⁸⁴⁴ and labyrinthodonte have been found, and indicate a Keuper or Rhætic age.

(3) The *Wianamatta Stage* consists chiefly of shales, but there are occasional bands of sandstone and thin coals. Fish-³⁴⁴ and labyrinthodont-remains (*Cyclotosaurus*) are found in it together with abundant plant-remains, including *Thinnfeldia odontopteroides*, *Tamiopteris* (*Macrotceniopteris*) *wianamattæ*, *Cladophlebis australis*, *Podozamites*, etc.

In the north-east corner of New South Wales the *Clarence Series*¹¹⁷ of fresh-water beds is developed and passes into Queensland. This series, which is divided into three stages, contains several seams of coal (Killarney Coal-Measures) and has a total thickness of over 3700 ft. The flora is slightly different from that of the Hawkesbury Series (which it resembles lithologically), but is quite similar to that of the Ipswich beds of Queensland (see below). The beds are usually referred to the Jurassic, but the lower part David¹¹⁸ correlates with the Rhætic. The characteristic and most abundant fossil is *Tceniopteris daintreei*, which is apparently identical with *T. spatulata* of the Indian Upper Gondwana. Coal-seams mark the lower part. In the West Darling district there are grits, sandstones, and conglomerates near Tiboo-burra which have yielded Jurassic plant-remains (*Tæniopteris* and *Taxites*). The conglomerates in one place are auriferous²⁴².

The so-called *Artesian Series*¹², which crops out along the western edge of the New England Tableland, and dips westerly under the Cretaceous of the central plain, is correlated with the Clarence Series, and the sandstones form the intake beds of the great artesian basin of Central Australia, if we regard the source of the water to be meteoric^{35 266}.

Overlying the Hawkesbury sandstones on the Talbragar River are thin fresh-water cherty shales and siliceous ironstones, of which the former are crowded with fish- and plant-remains. The flora is much like that of the Clarence Series, and the plant *Podozamites lanceolatus* is particularly abundant; the fish³²² are said to resemble those of the Liassic and Jurassic of Europe. The commonest genus of fish is *Leptolepis*.

Queensland^{24 79}.—Beds of Lower Mesozoic age occur on both sides of the dividing ranges, and pass westward under the marine Cretaceous of the central plains. The greatest development of Upper Triassic rocks is in Queensland⁷⁹, according to David¹¹⁸, and it includes important coal-deposits. The lowest beds constitute the *Esk Series*^{221 227 329}, and consist of terrestrial lava-flows and andesitic and trachytic tuffs containing burnt remains of the tree *Cedroxylon*. There are also in the same series calcareous sandstones and conglomerates containing fern-remains (*Sphenopteris*, *Cladophlebis*, *Ginkgo*, *Thinnfeldia*, etc.). The Brisbane tuff²²³ is referred to the Upper Triassic by some geologists.

The *Ipswich Formation*²²⁹, which is referred to the Trias, is typically developed round the town of Ipswich in the south-east corner of the state. The beds mostly consist of fine conglomerates, grits, white, grey, and brown sandstones and shales, with a number of good coal-seams and layers of fire-clay. At Brisbane they yield important supplies of artesian water, and contemporaneous lava-flows are interbedded in places. The fossils comprise terrestrial plants, insects, and fresh-water shells (*Unio*). Amongst the plants are *Thinnfeldia odontopteroides*, *Cladophlebis denticulata*, *Tceniopteris*, and several species of *Ginkgo*, *Baiera*, *Podozamites*, and *Pterophyllum*. On the evidence of the flora Walkom⁸⁰ regards the Ipswich Series as Triassic, and David¹¹⁸ correlates them with the Wianamatta of New South Wales. In the Bo wen basin the so-called Carborough Series is apparently of Hawkesbury age.

There is also a younger series of beds in south-east Queensland which is known as the *Walloon Series*, possessing a slightly different flora; it has been regarded as probably homotaxial³²⁹ with the Liassic or Lower Oolite of Europe⁶⁰, but David¹¹⁸ considers that it embraces the whole of Jurassic time,

and is equivalent to the Clarence Series of New South Wales. It has typically a thickness of 6000 ft., and is divisible into several stages. It is lacustrine in origin, consisting mainly of soft sandstones and shales with plant-remains. At the top are important coal-measures. A giant dinosaur⁹⁴, *Bhctooaurua brotmei*, has been discovered in the lower part of the series.

[The *Burrum Coal-Measures*²⁹ and those at Maryborough and on Frazer Island are now generally considered to be of Cretaceous age, but since part of the Jurassic fauna and flora survived till Cretaceous times there is consequently an intermixture of fossils in these beds.] (See below.)

In **Victoria**^{31 40} the Permian seems to be disturbed only in the neighbourhood of Tertiary faults or monoclinical folds, and usually the Trias-Jura Formation, known as the *Tœniopteris Beds* or Carbonaceous Series, follows it without a break. Chapman has²¹⁴ described a Triassic flora from the upper part of the Bacchus Marsh beds at Bald Hill, where the beds have a very limited outcrop. Upper Gondwana species of plants occur in these shales and sandstones. The *Tœniopteris Beds*, which are exposed at the surface in three areas—the western or Wannon area, the central or Otway area, and the South Gippsland area—consist of shales, mudstones, and felspathic sandstones, largely composed of the debris of volcanic rocks, with some coal-seams which in South Gippsland range up to 10 ft. thick, but are thin elsewhere. They contain typical plant-remains²²⁹ of the Jurassic, such as *Tœniopteris daintreei* (-*T. spatulata*), with a few fresh-water shells (*Unio*) and occasionally fish and reptiles. The Wonthaggi Coal-Measures, Cape Paterson Beds¹⁷⁷, and Otway and Wannon Series, which yield plant-remains (*Equisetites*, *Coniopteris*, *Brachyphyllum*, etc.), are referred to the Jurassic.

In **Tasmania**^{25 37} the Mesozoic fresh-water beds, including the so-called Upper Coal-Measures ' or *Fingal Series*, rest in places conformably on the Permian Upper Marine beds which are almost horizontal, and there is no apparent physical break. The lowest Triassic beds in Tasmania are the *Moss Sandstones*, containing *Vertebraria* and the oldest Australian reptile. These are followed by the Knocklofty and Rhyndaston Sandstones, but their correlation with the Hawkesbury Series is doubtful. The *Productive Coal Measures* are of Upper Triassic age like the Wianamatta Series and have various local names. Tuffs occur in the Upper (Triassic) Coal-Measures in the New Town Coal-Basin, proving contemporaneous volcanic activity²³⁴. The Fingal beds are chiefly composed of sandstones, and are estimated to be about 1200 ft. thick. They contain seams of good coal up to 20 ft. in thickness, and extend through the central, south-eastern, and eastern districts. The Jerusalem coalfield is one of the best known. The flora includes *Thinnfeldia odontopteroides*, *Alethopteris* (*Cladophlebis*) *australis*, and other plant-remains of Triassic rather than Jurassic types, though Howchin⁷¹ considered the Fingal Series to be referable to the Jurassic. There are many other coal-fields, including the Mount Nicholas, Dalmaine, Douglas River, Avoca, etc. The Knocklofty and Ida Bay Series, near Hobart, of which the former contains some fish and labyrinthodont-remains, are supposed to be older than the Coal-Measures.

It has been suggested that the great sills of diabase, often over 600 ft. thick, which penetrate these coal measures in Tasmania, belong to the same period of eruption as the similar great sills in South Africa, and therefore are of Upper Karroo age. The foyaitic rocks of Port Cygnet, which intrude the Permian, are considered to be of Lower Mesozoic, possibly Jurassic, age.

In **South Australia**⁷¹ we find in the Leigh Creek^{17 42} area, east of Lake Torrens, several connected basins of erosion holding lacustrine beds of blue clay and shale, interstratified with clay-ironstone, limonite, and seams of

poor coal up to 47 ft. thick. The whole thickness of the series reaches 2000 ft. The plant-remains include the typical species of *Thinnfeldia* (*T. odontopteroides*), *Macrotrcmiopteris wianamattæ*, *Phyllopteris feistmanteli*, *CladopMebis*, *Podozamites*, etc. The lamellibranch *Unio eyrensis* is very abundant. These beds are of Triassic age, according to the palæontological evidence.

In the **Northern Territory** the Jurassic beds cover large areas and consist chiefly of sandstones which have yielded a few plant-remains.

In **Western Australia**^{83 74} the Jurassic rocks, which are of peculiar interest, being marine, have a fairly extensive development, but occur chiefly as a coastal strip in the Champion Bay district between Perth and Geraldton. The beds have been proved by bores to have a thickness of 2000-3000 ft., and rest with a marked unconformity on the Permian rocks of the Irwin River Valley, forming dissected tablelands near the coast. These beds extend northwards to Sharks' Bay, and are found in the Gascoyne River district. They are also said to be found near Cape Riche, and beyond Phillips River on the south coast.

The beds are largely of marine origin, and thus differ from all the other known Australian occurrences of Jurassic age; they contain a considerable molluscan fauna⁵⁴, indicating several Jurassic horizons. Oolitic limestones, clays, ironstones, sandstones, grits, and conglomerates occur and contain in many cases fossils specifically identical with those in the Lias and Oolites of England⁴⁸. Amongst the Liassic ammonites are *Am. moorei* and *Am. walcotti*, and amongst the lamellibranchs are *Myacites liasinus*. The Oolitic species include *Am. macrocephalus*, *Avicula* (*Pseudomonotis*) *echinata*, *Avicula miinsteri*, *Lima pectiniformis*, and *Trigonia costata*. These seem to be the only marine Jurassic beds known in Australia.

Some plant-remains, including *Tceniopteris daintreei*, *Podozamites*, *Neuropteridium*, etc.⁸⁰, which occur near Minginew, seem to indicate the equivalence of the beds which contain them to those of Talgai and Rosewood in Queensland.

CRETACEOUS²⁷⁴

Queensland^{24 79}.—An enormous transgression of the sea took place over the centre of Australia in Cretaceous times, and a marginal strip of the western coast was also submerged. The severance of east Australia from west Australia was complete. This epicontinental sea or Cretaceous Mediterranean is characterised by many peculiar species of fossils, and by some molluscan genera (*Maccoyella*, *Pseudavicula*) which are restricted to this region. The precise limits of this sea on the south and south-west are not at present known.

The *Moiling Downs Formation*²⁷¹ covers about three-quarters of the surface of Queensland and extends inland to the west and to the south-west over an immense area passing into South Australia and New South Wales, and forming undulating plains of the Great Artesian basin. It consists almost entirely of marine beds, including shales, often concretionary, clays, marls, concretionary limestones, and calcareous sandstones containing calcareous concretions. Glauconite renders many of the sandstones green. Some thin coals also occur in it. The total thickness of the formation is at least 2000 ft. Two main series of beds are now distinguished within the Rolling Downs Formation on lithological and palæontological grounds^{78 118 142 227}. The lower or *Roma Series*²⁹ comprises chiefly bluish clays with calcareous concretions characterised by special genera of ammonites^{78 78a}, such as *Australiceras*, *Toxoceratoides*, *Tropæum*, *Aconeceras*, *Sanmartinoceras*, and *Aioloceras*. It may be correlated with the Aptian. The fauna is said to be most like that of corresponding beds in Patagonia, north Russia, and Spitzbergen. There

is also evidence of a glacial episode⁸⁰ in the Roma Series in the presence of erratics up to 6 ft. in diameter. The Upper or *Tambo Series*³²⁹ of the Rolling Downs Formation consists mainly of yellowish limestones, and contains ammonites of the genera *Puzosia*, *Beudanticeras*, *Prohysterocheras*, *Inflatoceras*, *Hamites*, etc., and is referred to the Upper Albian. In the Cape York Peninsula, Queensland, beds containing plant-remains are also referred to the Aptian. Other fossils in the Rolling Downs Formation are species of *Psettdavicula*, *Maccoyella*, *Inoceramus*, *Belemnites*, *Plesiosaurus*, and *Ichthyosaurus*. The formation is of great economic importance, for it forms the impermeable cap under which are imprisoned the stores of water²⁶⁸ which are usually considered to maintain the flowing wells of western Queensland. The Maryborough marine beds³²⁹ are the eastern equivalents of the Roma Series of the western plains, and contain a nearly similar marine fauna, including *Micraster* and *Maccoyella*³¹⁰.

The sandstones, shales, and coal-seams of the *Burrum Coalfield*, which are now referred to the Cretaceous instead of to the Jurassic, rest in places directly on these Cretaceous marine beds, but they are said to possess an intermixture of species of both periods. This '*Burrum Series*'³²⁹ occupies the coast-line for a distance of about 175 miles from Point Arkwright. The plant-remains of the Burrum Series include *Phyllopteris feistmanteli* and species of *Alethopteris*, *Teniopteris*, *Pterophyllum*, *Ginkgo*, etc., and the fresh-water shell *Corbicula*. The Styx Coal-Measures³²⁹ follow on this Burrum Series north of Rockhampton, and are of Albian or Cenomanian age.

The Uppermost Cretaceous beds in Queensland are referred to the Cenomanian and are known as the *Winton Series*^{227 329}; they have a thickness of 3000 ft., and consist of sandstones, clays, and lignites, with a few plant-remains, and are included in the so-called 'Desert Sandstone,' a name which has been dropped, the Tertiary *Eyrian Series* (see below) having been separated off from the group of beds formerly comprised under this name. Locally there are conglomerates and thin coals, and trachytic tuffs are said to be associated with the lower beds near Port Mackay. By secondary processes the surface of the sandstones is often converted into quartzite, and opal of many kinds is a common product of the silicification.

The mode of deposition and origin of the beds comprised under the name of the Desert Sandstones have been much discussed; some of the formation may be of aeolian origin, but most of it was probably laid down in a series of lakes or lagoons connected with the sea.

The recent discovery of a Tertiary flora in parts of the Desert Sandstones of this province (see below) proved that some of the beds are not of Cretaceous age, as was previously believed.

In South Australia^{71 142} and the Northern Territory²⁰³ the general character and development of the Cretaceous beds are similar to those in Queensland, and the fossils are most identical. The beds, as in that State, are nearly or quite horizontal, and maintain a remarkable uniformity of character. In Central Australia we meet also with evidence of contemporaneous glacial conditions in beds corresponding to the Roma Series of Queensland. For large erratic boulders^{80 85} are found in sandy mudstones along with marine fossils. The glaciation was not intense, but the coldness of the seas is indicated by the character of the fauna, as Whitehouse²²⁷ has pointed out; the large size of the tree trunks in the boulder beds does not suggest extreme conditions.

In **New South Wales** the Aptian Cretaceous beds are found with the same general characters, but are limited to the north-western areas. At Tiboburra¹¹⁸ calcareous shales containing the typical molluscan genera *Maccoyella* and *Belemnites*, together with large erratics, have been found in the beds,

which are spread over an area of 40,000 sq. miles. The Roma Series crops out extensively in the north-west of the State, and the beds are likewise nearly or quite horizontal. Though much denuded, the formation reaches a thickness of 500 ft. It yields the characteristic marine fauna, and at White Cliffs contains large boulders of fossiliferous Devonian quartzite. In the same locality the organic remains have frequently been replaced by opal. In the White Cliffs district the glacial erratics in these Cretaceous beds are exposed *in situ* in the opal workings^{242 244}.

Victoria and much of the eastern portion of Australia formed an area of dry land during Cretaceous times, and no contemporaneous marine or other deposits are known to occur *in* these parts. But local igneous activity seems to have prevailed, for the post-Triassic dykes, sills, and laccolites, including many of the alkaline intrusions, probably belong to the close of the Mesozoic.

In some parts of **Western Australia** marine conditions prevailed. Representatives of the Aptian are found with characteristic fossils on the Transcontinental Railway, and Upper Albian and Cenomanian beds, with radiolaria, are represented on Melville Island, Darwin, and Fanny Island in the extreme north. But though the southern or Eucla district may have formed part of the great epicontinental sea, yet the western coastal belt has beds with such distinctive faunistic characters that it is probable that they accumulated in a separate basin. In the Gingin^{44 274} area on the west coast, the Cretaceous rocks are represented by white chalky limestones^{53 63}, with glauconitic marl and clay-shale below, and at the top a ferruginous sandstone. These beds extend north of Perth along the coast to the Murchison River, and are the latest Cretaceous beds in Australia²⁷⁴, for they contain Santonian fossils, such as *Marsupites*, *Micraster*, *Unitacrinus*, etc., with many foraminifera and ostracoda^{58 63}. The fauna is comparable with that of the Ariyalur beds of southern India.

In the south, beneath the Eucla Limestone (see below) of Tertiary age, which covers an immense area in the Nullarbor Plains north of the Bight, Cretaceous rocks have been pierced in bores which seem to be equivalent to the Rolling Downs Formation of north-eastern Australia, so that the Gingin beds of the west coast belt are palæontologically distinct.

Tasmania.—Tasmania, like Victoria, seems to have been a land-area in Cretaceous times, but the end of the Jurassic or Mesozoic or the beginning of the Tertiary, was likewise marked here³⁷ by igneous activity, represented by the intrusion of great sheets and dykes of olivine-free diabase which have penetrated all the rock-systems earlier than the Tertiary. Most of the coastal promontories in the south-east and west, and many in the north are formed of diabase, while in the half of the island east of the central tableland rocks of this nature are widely exposed by erosion. Whether these are of Trias-Jurassic Upper Karroo age, as in South Africa, or of late Cretaceous age (as in the Deccan) is uncertain.

Tectonics.—The latest orogenic movements affecting Australia occurred along the Queensland coast in post-Cenomanian times (apart from local less intense folding in Tertiary times). The pressure appears to have been from E.N.E. to W.S.W., and it is possible that these movements coincide with the Laramide 'revolution' in North America.

TERTIARY^{21, 230 231 323}

At the close of the Cretaceous there was a fresh uplift of most of the Continent, but in the south there was a submergence which allowed the Miocene

seas to invade much of southern Victoria and of the adjoining parts of New South Wales and of South Australia, and also the north of Tasmania. The largest area over which marine deposits were spread was apparently in the region north of the Great Australian Bight. With these exceptions the Australian continent seems to have been above sea-level and to have had its main outlines unaltered since the end of the Cretaceous period.

The great inland basin which extended over part of the land-area seems to have first suffered extensive denudation accompanied by the deposition of widespread fresh-water deposits represented partly by much of the so-called 'Desert Sandstone Series.' A further elevation in Pliocene times reinvigorated the drainage, and the beds were dissected and assumed the form of 'mesas' and 'buttes,' which are the chief types of relief in Central Australia to-day⁷¹. The recent discovery of an exogenous flora with an early or Middle Tertiary facies in the upper part of the Desert Sandstones of Queensland, forming the Eyrian Series, throws important light on the age of this formation and the physical history of this region. All the known Tertiary beds in Queensland are of fresh-water origin. The southern area alone affords us an insight into the Tertiary marine history of Australia.

Eocene to Pleistocene.

The classification of the Tertiary beds of Australia and their correlation with the members of the European sequence are still matters of discussion²¹⁶. No system of nomenclature finds universal acceptance, but Chapman's scheme^{46 46 283 823} for the marine deposits, which is here adopted, is as follows :—

4. Werrikooian Series=Upper Pliocene.
3. Kalimnan „ = Lower Pliocene.
2. Janjukian „ — Miocene.
1. Balcombian „ — Oligocene.

A different nomenclature and classification has been proposed by Singleton²²⁶ 230 231 for the development of the Tertiaries in Victoria, but the general scheme is the same, except that the Balcombian as well as the Janjukian is referred to the Miocene, and the Oligocene is considered to be represented only by lignites, clays, and sands in parts of Gippsland and is termed the *Yal-lournian*.

The whole Tertiary Series is partly marine and partly fresh-water or estuarine. In the Balcombian, which seems confined to the State of Victoria, the foraminiferal genus *Amphistegina* (formerly erroneously identified as *Nummulites*) is predominant. The polyzoal beds of the Janjukian (known also as the Aldingan), which abound in *Cellepora gambierensis*, yield the characteristic Miocene genus *Lepidocylin*, and the marls contain the Miocene cephalopod *Spirulirostra*. In the Kalimnan Series Cetacea of the Pliocene Crag of England and Belgium are characteristic. The Werrikooian, which contains almost exclusively living species of the southern coast, has its typical section at Limestone Creek, Glenelg River. Of the foregoing the Janjukian is by far the most important. The Tertiary marine molluscan faunas of Australia were earlier described by Tate¹²¹, who termed the Oligo-Miocene beds 'the Older Tertiary.' Chapman⁸⁴ and others have added greatly to our knowledge of the fossils and of the succession of beds.

It is in Victoria and the adjoining coastal regions of South Australia that these series of marine beds have been most studied, but they extend into the Murray Basin of New South Wales. In Tasmania similar beds are well developed on the north coast¹²⁹. No marine equivalents have yet been proved to exist in any part of Queensland.

In addition to these marine deposits there is a large development of volcanic rocks of Tertiary age in most parts of southern and eastern Australia^{124 271}, chiefly consisting of flows of basaltic lava associated with fresh-water and terrestrial beds of considerable thickness and of economic importance owing to the occurrence of seams of lignite or brown coal. Two main periods of volcanic activity²⁹⁴ can be generally recognised, and their lava-flows are often termed the Older and Newer Basalts. The Older ones are of Oligocene age for the most part.

In Pliocene times¹¹⁸ there was a remarkable development of volcanic rocks of alkaline character, which have been traced from Tasmania to north Queensland. These have been most studied in the Mount Macedon district, Victoria^{105 134 184 185 239 268}, and include anorthoclase-trachytes and several other peculiar types of rock.

The terrestrial and fresh-water deposits of Australia contain a rich flora which in early Tertiary times is considered by Von Ettingshausen to include the elements of all the living floras of the world, and to have become gradually differentiated and modified by extinction or migration.

The general sequence of events in Tertiary time in the southern part of Australia, according to Edge worth David^{5 118}, seems to have been as follows : (1) Accumulation of plant-bearing strata and lignites; (2) outpouring of the older basalts; (3) submergence of land-areas along the southern shore of the continent, accompanied by deposition of marine beds rich in *Cellepora gambierensis* (Miocene); (4) deposition of the *Ostrea sturti* beds (Lower Pliocene) in the lower Murray Basin; (5) outpouring of alkaline lavas²³⁹ and tuffs along an immense belt of country from Victoria to Queensland; (6) formation of Pliocene fresh-water beds and of marine beds near Adelaide, accompanied and followed by (7) extensive outflows of basaltic lavas²⁷¹; (8) warping of the eastern periphery of Australia; (9) ice-age and pluvial period; (10) formation of rift-valleys and faults across the highlands.

(1) Victoria^{86 226 267 298}.—The Tertiary Series in Victoria begins with a succession of clays containing thick beds of brown coal, though the precise geological age of many of these beds has not been definitely fixed. This *Brown Coal Series*¹¹³, which represents terrestrial conditions prior to the submergence and to the invasion of the Tertiary sea in southern and south-eastern Australia, is followed by the Oligo-Miocene marine series, which consists of limestones, marls, clays, and sandstones, and extends along the south coast as a series of isolated patches running up into the interior in a succession of gulfs. At Altona a brown coal-seam 140 ft. thick underlies the Oligocene (Balcombian). The Mornington leaf-beds are also referred to this horizon, and near the same place the Older Basalts rest on the Balcombian. Marine Miocene (Janjukian) at Flinders rests on the Older Basalts which have here been proved to be over 1300 ft. thick. The fresh-water deposits beneath the Older Basalts consist of white clays, ferruginous sands, gravels, and lignites or brown coals. Probably the great lignite deposits of Lal Lal are of this age, and in the Latrobe Valley¹⁷³ in Gippsland there is a thickness of 780 ft. of brown coal, which was passed through in a bore of a depth of 1010 ft. These are referred to the Oligocene (Yallournian) by Singleton²³¹.

The **Balcombian**, with a marine facies, is typically developed at Balcombe's Bay on the east shore of Port Phillip, and the lower beds of blue clay at Muddy Creek near Hamilton may be likewise referred to this series. The stratigraphy of the marine Tertiaries in Gippsland has been described by Crespin²⁹⁸. Chapman^{6 288} includes the above-mentioned estuarine and fresh-water beds and the brown coals with the Balcombian, but some of these fresh-water beds may be of Eocene age. The Balcombian deposits of Port Phillip have yielded a great variety of genera and species of foraminifera³⁰².

The **Janjukian** is typically developed on Bass Strait in the parish of Janjuc, north of Geelong. At Muddy Creek polyzoal limestone of this age overlies the Balcombian blue clays. The Batesford Limestone containing *Lepidocyclus*, etc., is referred to the Janjukian, and there are flows of basalt which are interbedded with these marine deposits. The foraminiferal genus *Lepidocyclus*, which plays an important part in the formation of some of these limestones, is characteristic of the Oligo-Miocene beds of Java, Borneo, New Guinea, Panama, and Europe. There is a species of *Aturia* in the beds, which is identical with the European Miocene shell *A. aturi*. The characteristic echinoids also have an essentially Miocene stamp, and in the Bairnsdale beds gigantic species of *Clypeaster* occur. Numerous large species of *Cyproea* are a feature in the Gellibrand and Muddy Creek deposits, and polyzoal limestones rich in *Cellepora gambierensis* are abundant. Many of the Balcombian fossils range up into the Janjukian, but the calcareous facies introduces new elements.

Of Janjukian age Chapman regards the leaf-beds of Sentinel Bock, Cape Otway¹⁸⁶, Maddingley (with remains of cinnamon, laurel, *Sterculia*, etc.), Bacchus Marsh, Pitfield Plains, Narracan, Dargo Hill Plains, and the older 'Beep Leads' (see below).

The Older Basalts^{105 184 271 294}, constituting the Older Volcanic Series, are not all of precisely the same age and cannot be referred to any single marine stage. They are most abundant to the east of Melbourne; some remnants occur on the ancient raised peneplain up to a height of 5000 ft., but they are more extensively found at lower levels in South Gippsland. There are no well-marked points of eruption. According to Chapman these Older Basalts belong to the Balcombian, Janjukian, and even Kalimnan periods. In places they clearly underlie the Janjukian and are therefore in those cases Oligocene in age. The commonest type of lava¹⁰⁵ is an olivine-labradorite basalt¹⁸⁵. In places tuffs and agglomerates occur, and the eruptions must have been spread over a long period. In Gippsland flows amounting to 1100 ft. in thickness have been struck in a bore^{134 185}.

The **Kalimnan Series** (Lower Pliocene) is typically developed near the township of Kalimna, Gippsland Lakes, in eastern Victoria²²⁶, and the fauna includes extinct genera of mollusca, as well as a very high proportion of extinct species. *Ostrea* is a characteristic genus, and often extremely abundant. *O. sturti* is a common species. In the Hamilton district, where the Kalimnan is well seen in section overlying the Janjukian and is itself capped by some of the Older Basalts, the most complete sequence of the Tertiary strata is exhibited; it is also present in the deep boring at Sorrento. The Mallee bores, where over 3000 ft. of Janjukian Limestone was passed through, illustrate the gradual passage of the Janjukian into the Kalimnan, but current-action is indicated by a nodule bed at Beaumaris, and in South Australia there is a distinct unconformity.

Chapman refers the *Newer 'deep leads'*¹⁴ or ancient river-gravels of Victoria²²⁶ to the Kalimnan; these deposits are gravels which lie in old water-courses cut out of older rocks, or are spread over the plains, and they are frequently richly auriferous. They are capped by the *Newer Volcanic Series*¹⁰⁵, W4 185 271 294 which consists of basalts of various types (known as bluestone) with interbedded clays and lignites. These basalts are mainly calcic olivine-basalts. This series of lavas includes limburgite and alkaline types⁹, and in the Macedon district²⁸⁸ the alkaline volcanic rocks are very varied in petrological character^{106 185}; Summers²⁶⁸ mentions solvsbergites, anorthoclase, trachytes and basalts, limburgites, and other types, but their order and succession are undetermined. Many of the flows issued from fissures, but the plains of lava are often dotted with small cones. Amongst the larger volcanic vents are Mount Elephant and Noorat, which are only recently extinct, and

there are many denuded stumps on the western plains near Camperdown and Mortlake. These volcanics spread into New South Wales and Queensland (see below).

(2) In **South Australia**⁷¹²⁸³ the Tertiary deposits of the Mount Gambier District²⁸⁸ are an extension of those of the Mallee of Victoria, and were deposited in the same gulf, which extended several hundred miles inland.

The Balcambian Series has not so far been distinguished in South Australia. But there is a series of sandstones and shales of fresh-water origin overlying unconformably the Cretaceous Winton Series which is referred to the Eocene and forms the so-called *Syrian Series* containing dicotyledonous plants and fish-remains. The siliceous crust resulting from secondary cementation of the arenaceous deposits when broken up forms the so-called 'gibber-plains'.¹¹⁸ This series was by earlier writers included in the 'Desert Sandstones,' as above stated. The Brown Coal beds of Moorlands²²⁴, near Adelaide, are of Lower Miocene age, and lie below the Polyzoal limestones (Janjukian). The Miocene (Janjukian) deposits, which are frequently termed the Aldinga from their good exposure in Aldinga Bay, have had a wide extension, though now reduced by denudation and faulting. They consist mainly of calciferous sandstones, argillaceous limestones, polyzoal limestones, and a chalky limestone with flints⁷¹, and are often richly fossiliferous⁸⁴. On the Bunda Plateau, and in the sea-cliffs of the Great Australian Bight, they are of a chalky nature, and in Gulf St. Vincent and Aldinga Bay there are good exposures of marine limestones containing *Turritella aiding* α and many other gastropods and bivalves. Some of the limestones are composed of polyzoa (*Cellepora*), or of nullipores (*Lithothamnion*), as at Hallett's Cove¹³² and on the Nullabor Plains⁸⁴. The Mount Gambier limestone also belongs to this age, and a similar rock is found on Kangaroo Island. After a slight stratigraphical and faunistic break the Janjukian is succeeded by the Kalimnan (Lower Pliocene) beds, which are calcareo-arenaceous in character and of less thickness and extent than the Miocene. They are exposed in the cliffs of the Great Australian Bight, and of Gulf St. Vincent, and along the Murray River, where oyster-beds with *Ostrea sturti*, etc., are characteristic. The Upper Pliocene (Werrikovian) is found only in bores near Adelaide, having been deposited in a narrow sunken trough; the fossiliferous marine sands of which it is composed reach a thickness of over 300 ft., but the submergence was merely local and restricted to the rift. About 20 per cent, of the species are Recent forms, but 50 per cent, are peculiar, and 30 per cent, occur in the Lower Pliocene. Some river gravels are also of this period.

(3) In **Tasmania** we find fresh-water lacustrine or terrestrial beds of Tertiary age apparently belonging to an older¹²⁹ and a younger series, as in the case of Victoria; the older beds are accompanied or succeeded by a great outpouring of basaltic lavas²⁷² and tuffs of varied character. Marls, sands, gravels, leaf-beds, and lignites belonging to this older series attain a great thickness in places, as for instance in the Launceston district, and fill ancient basins on the surface. The flora is said to show a mixture of European and Australian forms. At Geilston a marsupial bone-bed is found between two lava-flows. The marine deposits¹²⁹ occur in isolated patches on the northern coast, and the exposures at Table Cape and Wynyard are amongst the best known. These are of Miocene (Janjukian) age. The beds are nowhere more than 80 ft. thick, and consist of shelly limestones, calcareous sandstones, etc. Many of the fossils are identical with those on the mainland. The lowest beds at Table Cape are characterised by the genus *Crassatella* and the upper beds by the genus *Turritella*; in the latter beds land-plants and the oldest known Australian marsupial (*Wynyardia*) also occur²⁸⁷. The whole group is capped by alkaline lavas, nepheline basalt, etc., as at Port Cygnet, similar to those of Victoria.

The later Tertiary deposits in Tasmania are all of fresh-water origin, and chiefly consist of clays, sands, and gravels or conglomerates, but the separation of the older and younger series is doubtful. Such occur in the Derwent Valley and in the Launceston Tertiary basin.

Most of the basalts in central and eastern Tasmania are considered to have been erupted in Upper Pliocene to Middle Pleistocene times²⁷². The alkaline basalts^{105 239} which occur at Table Cape, Shannon Tier, and elsewhere²⁷² probably belong to the same series of alkaline lavas as that in New South Wales, Victoria¹⁸⁴, and Queensland⁴⁸, and the small volcanic cones of nepheline basalt on the Shannon Tier point to late eruptions. It is possible that some of the intrusive plutonic rocks in Tasmania (*e.g.* the gabbros of Hobart) may be of Tertiary age.

(4) In **Western Australia** foraminifera of Eocene species are found in the limestones of the North-West Division²⁸⁴. The marine limestones of the southern region in the Eucla basin, which cover the Cretaceous beds, are of Janjukian age, as above mentioned, and they extend inland around the Bight for 100-150 miles. In addition to these Eucla polyzoan limestones there are siliceous shales and deposits in the Norseman, Albany, and Cape Riche districts forming the *Plantagenet Series*²²⁵ and containing mollusca and sponge-remains which are referable to the Lower Miocene (Janjukian). Some Pliocene marine beds also overlies the Eucla limestones. There are also Tertiary fresh-water beds of clay, sandstones, and brown coals on the Gascoyne River, the Fitzgerald River, and elsewhere, which have not been precisely correlated. The leucite lavas²⁹⁴ of the Fitzroy River and some of the basalts of the Kimberley region²⁰⁰ are also of Pliocene (Kallimnan or Werri-kovian) age. They include plugs, craters, and fissure-intrusions. In the south-west corner of the State around Bunbury and Flinders Bay, there are great Tertiary flows of basalt probably belonging to the later period.

(5) In **New South Wales**^{12 66 324} there are no marine Tertiary deposits, with the exception of the extension of the Victorian and South Australian marine beds which are met with in the Murray Basin. In the West Darling district²⁴² the older Tertiary is represented by the fresh-water or terrestrial formation of the *Eyrian Series* of Eocene age, consisting of sandstone, shales, and secondary quartzite, forming siliceous cappings. The *Murravian* (Middle and Upper Tertiary) beds of marine origin are exposed along the banks of the Lower Darling and Murray Rivers and in bores beneath the plains south of the Barrier Ranges. Species of *Trigonia*, *Pectunculus*, *Dentalium*, *Cancellaria*, etc., with sharks' teeth, have been found in them, and they appear to be of Miocene age. The fresh-water beds attain a great development. The older series consists of conglomerates, gravels, sandstones, clays, and ironstones, with leaf-beds and brown coals, as at Kiandra. The buried gravels of the old river-courses form the 'deep-leads' and are sometimes auriferous. These beds are covered by basalts and tuffs, often several hundred feet thick, and occupy some of the highest points of the Dividing Range. The flora is said to contain a mixture of European and Australian genera, and it was described as Eocene by Ettingshausen, but the generic and specific determinations are open to doubt.

According to Sussmilch¹² there are three distinct volcanic epochs in Tertiary times in New South Wales represented by (1) the Older Basalts, capping some of the hills as at Kiandra, and covering up the older lignites and 'deep leads'; (2) the Newer Basalts, forming extensive sheets on the surface of the tableland; and (3) the alkaline lavas and tuffs^{48 95 239} which are widespread like the basalts, but are marked by small groups of volcanic cones, as in the Canobolas Mountains on the western edge of the Central Tableland¹²⁴. Associated

with the latter are diatomaceous deposits. Probably the tinguaites near Lue and some other alkaline intrusives are of Tertiary age. In the Mittagong Bowral district there is an important series of alkaline lavas and intrusives invading the Triassic beds, and in places forming hills nearly 8000 ft. high, which represent the denuded plugs of old volcanoes. David and Skeats⁵ regarded all these extensive alkaline lavas and tuffs as Middle Cainozoic and older instead of younger than the Newer Basalts.

Of the younger fresh-water deposits the beds at Vegetable Creek are an example. The plants are said to be mostly very similar to those of the present-day coastal brush vegetation. Many of the newer 'deep leads' are stanniferous, or contain gem-stones.

In **Queensland** there are no marine Tertiaries, but a fresh-water and volcanic series³⁴², which is divisible into an older and younger group of beds, is largely developed. The *Eyrian Series* of Eocene age extends from South Australia and New South Wales into the central basin of Queensland³²⁹ with the same lithological and palæontological characters. In the centre it rests on the Cretaceous (Winton Series), but in the south-east on the Roma and Tambo Series. In the Moreton district⁹³ it is well developed. Beds of clay containing fossil leaves are associated with the flows of lava. Near Rockhampton the brown coal deposits are referred to the Miocene. The basalts of the older (Oligocene) series cover the 'Desert Sandstones' or older beds, while in places these had first been upheaved and denuded. There is a huge tableland of these basalts to the west of Walker River, and at the head of the Burdekin they are estimated to cover 2000 sq. miles of country. The sheets of lava are mostly horizontal, and occasionally the vents of the older series can be located, as for instance in the crater lake of Lake Eachan. Some of the gold-bearing drifts may be older than any of these eruptions.

The alkaline volcanic belt of New South Wales^{48 239 342} is prolonged in various ranges and dome-shaped hills through Queensland to the north-east of Rockhampton, and includes lavas and tuffs associated or interstratified with diatomaceous earths.

The Newer Volcanic Series of Pliocene age³⁴² is found chiefly north of Cooktown and in the Einasleigh and Lynd River districts, and the vents are more frequently preserved, forming hills or necks or crater-like hollows, or lakes, as in South Australia. The basalts are often scoriaceous, and tuffs and agglomerates may be associated with them. A series of hot springs and geysers in the Einasleigh district show that the volcanic activity has not completely died out.

Earth-Movements^{187 206}—The warping and faulting of the old Australian and Tasmanian peneplain⁵, which took place chiefly in post-Miocene times, as proved by the folded and uplifted Miocene beds in the Mount Lofty Ranges²³⁸ near Adelaide, began somewhat earlier in certain places, for some movements of a downward nature took place in Oligocene times, as is shown by the Lower Miocene marine beds of Victoria resting on the Older Basalts, which are perhaps of Eocene age, and were poured out on a land surface. The post-Miocene movements which deformed the older peneplain were differential and intermittent, and led to modification of the old drainage system. It is believed by some^{95 289} geologists that the tectonic lines of these late Tertiary disturbances are related to the extrusion of the above-mentioned alkaline volcanic rocks, but this connection is denied by others²⁹⁴.

According to Andrews⁶⁶ there were two principal uplifts in Tertiary times in the New England district, the earlier one to an extent of 1000 ft., followed by extensive peneplanation and outpouring of basalts, and the later one to an extent of 3300 ft. in Pliocene (?) times. The subsequent movements in that part have been of minor extent, and are mentioned below.

Pleistocene.

The close of the Tertiary period in south-eastern Australia was marked by the great epeirogenic uplift, which Andrews suggests took place in the Pliocene and affected all the southern part of the Continent, and probably included also the coastal highlands of eastern Australia⁸⁹. This has been called the *Kosciusko uplift*, and led to the formation of an extensive tableland which is now greatly dissected. It is probable that the present main Dividing Range in Victoria owes most of its elevation to the Kosciusko uplift, while the Flinders and Mount Lofty Ranges were raised considerably. The plateau was appreciably warped in eastern Queensland, and the interior subsided. This gives the Main Divide in this region a remarkable asymmetry¹¹⁸. This depression of the interior of the continent completely broke up the older hydrographic system, and led to the formation of interior drainage-basins below sea-level¹². It was accompanied in its later stages by extensive warping and faulting, and the formation of great fault-blocks and rift-valleys. Two such rift-valleys bound the Mount Lofty Plateau, that on the west descending in a series of step-faults to form the 'Rift Valley of South Australia.' Following on this upheaval came the Ice age, or period of glaciation in New South Wales^{20 41}, which occurred in late Pleistocene times, and was accompanied by a greater rainfall over the centre of the continent. The ice on Mount Kosciusko^{118 336} appears to have extended down to about 5500 ft., while now it does not come below about 8800 ft. This cold climatic period is thought to have led to the extinction of many of the mammals and to the modification of the flora. Moraines and glaciated surfaces at low levels bear witness to the former great extension of the glaciers in New South Wales, and there are also traces of a second less severe glaciation in the same district²⁰².

In Tasmania^{37 202 235} there is likewise evidence in the western highlands *fe.g.* around Mount Pelion and Mount Tyndall) and elsewhere, of a previous greater development of glaciers, and an older and younger series of moraines have also been recognised. The boulder-clays descend to a few hundred feet above sea-level. Recently²³⁵ Lewis has recognised four separate ice-invasions, the two middle ones apparently being phases of one stage. The lakes on the Central Plateau²³⁷ are due to glacial action during this period.

To the late Pliocene or Pleistocene, and partly or wholly synchronous with the Ice age, belong the widespread alluvial, swamp, or cave deposits containing the bones of living and extinct marsupials, some of large size, and of birds and reptiles, with occasionally shells of living fresh-water species of mollusca and teeth of the existing fish *Ceratodus*. The deposits point to a good rainfall with intermittent droughts on the central plains, and to the existence of the present system of internal drainage which was initiated by the Kosciusko uplift. They are found in Queensland, New South Wales, Victoria, Tasmania²⁸⁷, and South and Western Australia, and possess varied characters. The salt lakes in the interior, such as Lake Eyre^{198 199}, contain deposits of Upper Tertiary or Recent formation. Loams are common in the Lake Eyre^{168 119} district, and contain many mammalian³¹⁶ remains, including the extinct genera *Diprotodon*, *Thylacoleo*, *Nototherium*, and members of the living genera, *Phascolomys* and *Macropus*, as well as the extinct birds *Dromornis* and *Genyomys*. In Victoria, near Geelong, the bones are said to be associated with some of the latest volcanic rocks in tuffs and lacustrine deposits. The bone-breccias of the Gisborne caves in Victoria and also the caves in the Wellington Valley, N.S.W., likewise yield the bones of *Diprotodon*, etc. Most of the bone-bearing deposits in Queensland occur in valleys of rivers flowing westward from the Queensland highlands to the western plains, but there must have been great changes in the climate and rainfall since their formation. The bones occur in great quantities in local patches, as if around water-holes, and are

often deeply buried, even to the extent of 200 ft. No human remains or implements have been found with them. In Western Australia the mottled clays, ironstones, and conglomerates, with patches of brown coal, which rest on the Archaean plateau, also contain in places bones of *Diprotodon*.

In South Australia during some part of Pleistocene time, but probably at a late stage, there was an outburst of volcanic activity²⁶³ and a series of volcanic vents or puy's were formed, extending from Mount Schank to Mount Graham, including Mount Gambier²³⁸. The Mount Gambier eruption²³⁸ which broke through Miocene limestones is proved to be of late Pleistocene date by the associated ash-beds containing living species of local plants and bones of recent marsupials. Post-Tertiary vulcanism is also shown in northern Queensland and on the islands of Torres Strait by explosion-craters²⁹⁴ and many foci of eruption. Similar outbursts occurred in South Australia. But in south-west Victoria there are also numerous ash and scoria cones which have scarcely suffered any erosion, and also lava ridges of recent flows. The Henbury craters in Central Australia about 50 miles south of the MacDonnell Range are regarded as due to the fall of meteorites, and not to be of volcanic origin.

Of late Pleistocene or Recent formation are the ' Helix Sandstones ' occurring on most of the islands in Bass Straits up to the height of 100 ft., the similar consolidated shelly sand-dunes of South Australia containing the same genus, and the dune-limestones of the Victorian coast.

The surface ironstone-gravels and conglomerates of the interior and of Western Australia⁷³, the gravels, clays, sands, muds, and occasional lignites in Gippsland and elsewhere, the silts of the plains and the widespread deposits of laterite may all be referred to the post-Tertiary period⁷⁴. The laterites in Western Australia⁷⁴, of which there are three forms, an aluminous, a ferruginous, and a siliceous, are of considerable economic importance as sources of iron and aluminium. They range in age from Tertiary to Recent. The thin surface-formation known as ' duricrust ' is the result of a long dry period after a short rainfall on areas of low relief with practically no run-off for the water, and may be of the nature of laterite, kunkar, or quartzite, jasper or porcelanite, according to the nature of the underlying rocks. The sand-ridges in central parts of the continent¹³⁸ as well as the coastal sand-dunes are important Recent formations.

Raised beaches²⁸⁰ along the south and east coast of Australia and Tasmania point to Recent intermittent uplifts and oscillations in the level of the land, and the evidence of the erosion of the valleys likewise shows repeated elevations alternating with pauses in the movement. The valleys, which originated after the Kosciusko uplift, were drowned by Recent downward movements to a depth of 150-200 ft. St. Vincent and Spencer Gulfs, and the estuaries of many rivers along the eastern coast of Australia, are examples of such drowned valleys, for there has been a foundering of the coastal margin, followed by a smaller uplift^{201 207}. The wide coastal plain in the south-eastern portions of South Australia points to an elevation of a marginal strip of land which, in Mosquito Creek near Struan railway station, is marked by a beach 200 ft. above sea-level, 50 miles from the sea-coast. But westwards on the Gulf the elevation only measures about 12 ft. On the Victorian coast there was, on the other hand, a subsidence of the coastal regions, as for instance in Bass Strait, and it may have been complementary to the rise of the South Australian coast. The drowned valleys and coastal lagoons of eastern Australia also indicate a Recent subsidence of the continental shelf. It was on the platform thus provided that the corals of the Great Barrier Reef^{86 69 201 207 208 219 250 328} established themselves. In many places this reef does not stand on the edge of the shelf, but several miles landward from its margin,

and the platform continues southward beyond the termination of the reef. It is thought^{126 219} that the Great Barrier Reef marks the edge of a former coast-line. The recent submergence of the land is also shown by the numerous drowned valleys and estuaries which have resulted in the formation of many important harbours and ports, including Sydney Harbour. But there is evidence of a still later uplift of a minor extent, in the shape of Raised beaches, along the coasts of New South Wales and Queensland.

The islands on the coasts of northern Queensland^{126 208 297} are intimately connected in their distribution and shape with the fracture-pattern of block-faulting, resulting in the formation of quadrangular blocks²⁰⁶. This structure is seen along the coast from Cape York to Cape Melville and in the islands of Torres Strait. A long strip of the coast⁸⁹ was first cut off from the eastern mainland of Queensland by a longitudinal marginal fault, and this strip sank and was broken up by transverse²⁰⁶ faults resulting in the formation of a string of islands and submarine banks on which the Great Barrier Reef has been built up^{126 201 207 219 240 250 297}. Movements of minor extent, sometimes of depression, at other times of elevation, have affected the whole coastal region during Tertiary and Recent times^{89 201 207 240 255 280}. The question of the connection of Australia with South America via Antarctica in Cretaceo-Tertiary times, as suggested by some features in mammalian distribution, is discussed by Du Toit³⁰⁸ in so far as it affects the theory of continental drift.

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It is not possible to mention here more than a few of the principal mineral products and mining fields, for most minerals of economic importance are found to a more or less extent in Australia.

Coal^{49 50}.—There are three chief coal-bearing series of strata in Australia, *i.e.* the Permian, the Trias-Jura, and the Tertiary, of which the first is the most important. The principal Permian and Trias-Jura coal areas are situated along the eastern side of the continent, including Tasmania²⁴⁸, while the Tertiary coal-producing regions lie in the south-eastern parts.

New South Wales is the most important producer, and its chief Permian coal-basin extends for nearly 200 miles along the coast, and has a maximum width of about 100 miles from east to west. The total area of Permian Coal-Measures in this State is over 16,000 sq. miles. The chief coalfield of Permian age is the Central, which is typically developed in the Hunter area, the Greta, Tomago, and Newcastle Coal-Measures here being present. There are also in New South Wales the Gloucester, Ashford, and Coorabin coalfields of this age. The Mesozoic Coal Measures which occur on the Clarence and Richwood Rivers are of much less importance and **the coal is poor.**

In Queensland the chief coal-producing districts are in the central and southern parts of the State, the Dawson-Mackenzie coalfield yielding 50 per cent, of the coal, and belonging to the Lower Bowen Series ; the coal is high-class steam-coal and there is also much anthracite. In the Alpha-Galilee basin the Upper Bowen Coal-

Measures contain great reserves of coal. The Burrum (Cretaceous) and Ipswich (Triassic) formations of the Mesozoic contain many coalfields, and the Ipswich or West Moreton coalfield is one of the most important in the State. The coal-seams in the Jurassic Walloon Series which occur on three main horizons are more lenticular than those of the Trias. Some thin and indifferent coal-bearing beds are also found in the Rolling Downs Formation in Queensland and lignites of Tertiary age near Rockhampton.

In Victoria the chief coal-bearing series belongs to the Trias-Jura, and is principally developed in South Gippsland (Wonthaggi, Jumbunna areas), but the seams are mostly small and local. Tertiary brown coals¹⁷³ occur over large areas, and the deposits reach a great thickness in the valley of the Latrobe.

The Leigh Creek beds in South Australia are of Trias-Jura age, and one seam of coal is stated to be nearly 48 ft. thick. Tertiary lignites in this State are considerably developed on the Murray River and St. Vincent Gulf.

In Tasmania²⁴⁸ the chief coals come from the Permian and the beds lie in many different basins. Most belong to the Greta horizon. The Preolenna coal in the Wynyard coalfield on the north-west coast is the best in Tasmania, and three seams of kerosene shale are also met with in this basin. The so-called 'Upper Coal Measures' in Tasmania are of Trias-Jura age. The largest collieries are in the Fingal coalfields near the east coast, where there are eight seams up to 11 ft. in thickness. The value of the widespread Tertiary lignites on the island is only potential.

In Western Australia the Collie coalfield in Permian strata contains several seams of hydrous semi-bituminous coal.

Oil-Shales.—The oldest oil-shales occur in the Greta (or Lower Coal Measures) of the Kamilaroi Series of New South Wales^{110 205}, and the deposit is popularly called kerosene shale or torbanite²⁹⁶. This deposit owes its oil to masses of algae²⁹⁶. The thicker oil-shales occur in the Newcastle, or Upper Coal Measures²⁹⁶. In Tasmania¹⁷⁴ the oil-shale or tasmanite in the Mersey area is on about the horizon of the Greta Coal Measures. There is also an oil-yielding substance known as Pelionite, a jet-black brittle material, at Mount Pelion, but only as a thin seam. In Queensland the Walloon Series (Jurassic) contains oil-shales, and there are also Tertiary lacustrine oil-shales in the Baffin Creek basin of 6-10 ft. in thickness as well as near Gladstone and in the Dawson Valley.

Petroleum^{88 110 117 118 256 269 317}.—In spite of repeated efforts in many parts of the continent, petroleum has not been found in **commercial** quantities in the older rocks, though traces of it **and small yields have been** obtained in **various** places⁸⁶. A small amount of a

heavy type of mineral oil has been won from glauconitic Oligocene rocks from bores in Eastern Gippsland. The great basin in Queensland seems to offer the greatest promise²⁶⁹. Natural gas³¹⁸ occurs in various places, but does not necessarily indicate oil.

Phosphates.—In South Australia¹⁸² rock phosphate occurs associated with limestone, but aluminous and calcium phosphate forms beds intercalated in Cambrian or Pre-Cambrian rocks, and apatite is found in intrusive pegmatites. In Victoria there are the Mansfield phosphate deposits¹⁷², which are of similar character and are intercalated with fossiliferous Upper Cambrian slates.

Bauxite.—Extensive deposits of this substance occur in Tasmania³⁰⁷, resulting from the weathering of volcanic tuffs^{307a} and other rocks.

Precious Stones.—Sapphires are obtained from the surface gravels younger than the Tertiary basalts from which they were apparently derived in the Anakie sapphire field in Central Queensland.

Opal of many varieties is a common product of the secondary silicification of the Rolling Downs Formation (Cretaceous). Precious opal is found in the White Cliffs opal-fields^{244 310} of New South Wales, and at various places in Queensland and in the Stuart Range in South Australia. In the White Cliffs it occurs in veinlets in the Lower Cretaceous sandstones, and in vertical cracks and joints in the rocks at various horizons irregularly. The beds contain marine fossils and silicified wood, and are overlain by Tertiary siliceous quartzites.

Asbestos.—In the Hamersley Ranges of Western Australia³³⁷ there are blue asbestos-bearing deposits in the banded ironstones of the Nullagine Series. Banded cherty and carbonate rocks and quartzites are interbedded with the riebeckite- and crocidolite-bearing beds. Bands of granular iron-ore (haematite) and jasper also occur in the series, and there is a close resemblance to the Lower Griqua Town Series of South Africa.

Building and Ornamental Stones.—Amongst the numerous stones used for building purposes may be mentioned the Grampian Sandstone of Victoria, the Hawkesbury Sandstone of New South Wales, and the so-called 'Brisbane Porphyry,' a volcanic tuff, in Queensland¹¹⁵.

. In New South Wales various marbles of Silurian and Devonian age are quarried, and the Cambrian of the Mount Lofty Range in South Australia and the Carboniferous of the Rockhampton district in Queensland also yield valuable marbles.

Water-Supply^{72 118 266 288}.—One of the chief problems of economic geology in Australia is the water-supply, particularly in the interior of the continent where the surface-supplies and rainfall are very scanty²⁴². The origin or derivation of the water obtained from deep bores in the great Australian Artesian Basin⁷² in the east central part of the continent west of the Cordillera is a matter of dispute³⁶. Several theories are in the field. It is believed by some geologists to be of modern meteoric²⁶⁶ origin or to be partly residual in Mesozoic strata, or to be surface-water of Pleistocene times which has been retained by the older deposits, or to be of magmatic origin and from igneous rocks. The strata of Trias-Jurassic age which in Queensland are regarded as the intakes are usually believed to be the main source of supply of the water in the great interior artesian basin⁵. Many of the wells yield water of high temperatures and contain an unusually high percentage of dissolved salts. Gregory^{70 288} is of the opinion that the ascent of the water in the bores cannot be explained by the pressure of the water in the Queensland hills or by the simple artesian theory, but that the chief supply is from plutonic sources, and that the rise of the water is due to gas pressure and rock pressure. In addition to the Great Artesian basin, which has an area of approximately 600,000 sq. miles, David¹¹⁸ describes twelve other basins in other parts of the continent, of which the 'Desert basin' in the north of Western Australia has an area of about 130,000 sq. miles; its geological age is Permian, as is also the North-West basin and the small Collie basin. The other basins are mostly sub-artesian and of Tertiary age and much smaller, the Murray River basin being the largest.

Gold¹⁹⁷.—In New South Wales gold occurs under various conditions :—

- (1) In detrital deposits forming the alluvial leads of Recent, Tertiary, Cretaceous, or even Permian (*e.g.* at Gulong) age. The Tertiary deep leads beneath the basalt flows are the most important. There are also coarse conglomerates of Jurassic age in the Mount Browne and Tibooburra districts resting on Pre-Cambrian rocks and covered by Cretaceous beds which yield a certain amount of detrital gold²¹².
- (2) Disseminated through the solid rock, *e.g.* in the Hawkesbury Sandstone.
- (3) In veins, reefs or lodes intersecting Ordovician, Silurian, Devonian, or Carboniferous rocks. Maclaren believes that most of these auriferous areas are related to the intrusive Permian granites. In the Hill End Gold-field the veins are bedded with folded Silurian slates and volcanic tuffs

invaded by dykes and sills of quartz-porphyry, and he either in the black slates or at their contact with the igneous sills or tuffs. In the Wyalong Gold-field the auriferous reefs lie entirely in fissures in the zones of crushed or gneissose granite or tonalite. In the Lucknow Gold-field the auriferous ore occurs as chutes or bunches at or near the junction of a number of east and west veins crossing a main fissure running north-west to south-east, and having the hanging-wall of serpentine and the foot-wall of augite-andesite.

- (4) Impregnations, as in the Lyndhurst Gold-field, where submarine silicified tuffs have been impregnated by sulphidic solutions. Many intrusive igneous rocks also in various parts of the State are impregnated with gold.

In **Victoria**⁸² the western gold-fields are in the Lower Ordovician formation, and include the Ballarat and Bendigo areas ; the central or Silurian area includes the Walhalla and other fields ; the eastern gold-fields lie on the Upper Ordovician of Bulumwaal, Harrietsville, etc., and the metamorphic series of the Bethanga, Mount Wills and Cassilis districts.

The most productive regions are those of Ballarat²⁷⁶ and Bendigo¹⁰⁹. In the latter the quartz-reefs occur interbedded in the sharply-folded graptolitic Ordovician rocks as superposed 'saddle reefs' on the summits of the folds or as 'trough-reefs' in the synclines, as in the case of the Gold-bearing Series in Nova Scotia. In the Ballarat²⁷⁶ Gold-field the auriferous quartz-veins occur as 'flat-veins' or 'flows,' which on crossing the thin vertical lines of dark carbonaceous slate (called 'indicators') become rich, while they are often barren on each side. The strata here consist of highly-tilted and sharply-folded alternate layers of sandstone and shale or slate, 'which are affected by a complex series of faults comprising 'dip-faults' or 'cross courses' and strike-faults or 'slides.' Along the latter occur the most important ore-deposits. Dykes of felsite and a later series of dykes of limburgite traverse the Ballarat field. There is often an intimate connection between the auriferous ores and the igneous intrusions. Thus the dykes of felsite and quartz-felspar-porphyries are directly associated in gold reefs, and the same is the case with the diorites, gabbro-porphyrates and lamprophyres in many parts. All the igneous rocks are more or less altered and metasomatism has taken place. The above-mentioned 'saddle' or 'bedded' reefs are apparently independent of the dykes, though not far removed from intrusions of granodiorite⁸².

The alluvial 'deep leads' in Victoria were deposited by rivers **flowing north or south** from an east and west watershed, and have

been in many cases sealed up by the Older or Newer basalts and by fresh-water Tertiary beds.

In **Tasmania**²⁴⁸, as in Victoria, the auriferous reefs are chiefly in the Ordovician rocks, and are mostly fissures filled with quartz and free gold, and are not of much importance. But in the Mount Lyell field (see 'Copper') the gold occurs in the copper ores which form mineralised bands of schists or lens-shaped masses of very pure sulphides. Details of the various scattered gold-fields are given in the Bulletins of the Geological Survey of Tasmania¹⁸⁹. The formation of these auriferous veins was connected with the acid and basic igneous rocks intruded at the close of the Silurian or Devonian period.

In **Queensland** the principal gold-mining centres are Gympie in the south, Mount Morgan in the central district, and the Charters Towers, Croydon, and Etheridge fields in the north.

In the Gympie field the rocks are of Upper Carboniferous age (Middle Gympie Series), and comprise shales, limestones, sandstones, and conglomerates, with inter bedded lavas and tuffs and intrusive greenstones. The reefs cross all the beds of the series, but only where they intersect the black graphitic or anthracitic slate-zones (at least seven in number) are they auriferous. The gold is associated with many other minerals.

The Mount Morgan deposit, 25 miles south-west of Rockhampton, is of unique character^{5b}. The upper portion of the hill consists of a deposit varying from red and brown haematite on the one hand, to a spongy siliceous 'sinter' on the other. The ore varies much in its mineral characters; it may be a white sugary quartz-sand, or a silicified haematite or heavy ironstone, or a bluish-grey quartz or quartzite, or a friable sinter; but all the types are essentially composed of quartz, and the gold in them is pure and very finely distributed. Below the oxidised zone is the sulphide zone in which pyrites occurs, and below it there is the chalcopyrite zone in which the copper contents of the ore are more important than the gold. The size of the deposit is unique; the open cut, 360 ft. below the summit, had an area of 14 acres. The surrounding and underlying rocks which belong to the Gympie Series consist of limestones, banded clay stones and tuffs, more or less metamorphosed, for they have been invaded by masses of hornblende-granite and intersected by later dykes of porphyritic dolerite, which also cut through the ore-deposit. The intrusion of the granite metamorphosed the sedimentary series and impregnated the rocks with iron pyrites, containing small proportions of gold and copper. The later invasion by doleritic dykes was followed by solfataric action, and subsequently atmospheric agencies completed the series of changes in the

rocks. The spongy cellular rocks seem merely to have been produced by the weathering of sandstones or greywackes impregnated with pyrites, and there is nothing suggesting the infilled pipe of a geyser as has been maintained. But the precise mode of formation of the deposit is still an open question.

In the Croydon Gold-field the reefs occur in masses of hornblendic rock and felsite, both of which contain broad zones carrying graphite, calcite, siderite, and fluorspar; the occurrence of the graphite seems connected with that of the gold. In the Charters Tower field the reefs occur in the metamorphosed sedimentary rocks on the western edge of a large mass of granite, and the richest deposits occur where they are crossed by dioritic dykes. In the Claude River Gold-field, Cape York¹⁴⁰, the gold is associated with the iron-stone (haematite-magnetite) schists of Pre-Cambrian age, as in the Tennant Creek Gold-field in Central Australia¹⁴⁰. In the Woggaman Province²⁸⁶, Northern Territory, the gold is chiefly alluvial, but it occurs also in quartz-veins in the metamorphic rocks.

In **Western Australia**^{7-11 15 26 33 52 102 198 311 340} gold occurs in 'lode-formations,' or in the banded ferruginous quartz-rocks, or in normal quartz-veins. The rocks, which are intersected by the auriferous quartz-veins, are of Archaean or Pre-Cambrian age, and have been described here in previous paragraphs (see pp. 562-564). Gold is also found in residual and alluvial deposits. The metal occurs native, or in compounds with tellurium and other elements, or in association with other minerals. The 'lode-formations' are veined zones consisting of a large number of small fissure-fillings with a generally parallel strike, the associated rock being impregnated or replaced by the minerals. The lode-material chiefly consists of quartz containing auriferous pyrites, gold tellurides, etc. The country-rock is largely schists (hornblende-schists and amphibolites). The mineralised quartz-veins occupy planes of shearing parallel to the foliation or occur as massive lenticular bodies. The banded haematite-quartz-rocks are like those in Rhodesia and India, and enclose ore-bodies in the northern gold-fields. The auriferous conglomerates of the Nullagine Series are closely similar to the banket-reefs of South Africa, and seem to be secondary in origin.

Most of the auriferous deposits in Western Australia occur in more or less parallel narrow belts with a general north-west and south-east direction, and all are situated in the old crystalline or metamorphic areas, chiefly occurring in the altered igneous rocks, especially the diabases. The Kimberley and Pilbara^{7 140} Gold-fields in the north, and especially the Kalgoorlie^{102 198 311} and Coolgardie Gold-fields in the east, are amongst the best known.

In **South Australia** there are auriferous deposits in Pre-Cambrian rocks in the Barossa²³⁶ and Tarcoola Gold-fields, but they are of minor importance.

Silver.—(See under 'Lead-zinc.')

Tin.—Mount Bischoff^{75 190 248}, on the north-west coast of **Tasmania**, consists of Cambrian or Silurian slates, sandstones or siliceous argillites much contorted, shattered, and metamorphosed; they are traversed by a large stanniferous quartz-porphry dyke or system of dykes which have undergone topazisation, and in some cases tourmalinisation also, the formation of the topaz and tourmaline being synchronous with that of the cassiterite. The tin ore is scattered through the porphyry and through the adjacent slate. The greater part of the rich tin deposit at this locality represents the disintegration and alteration of the stanniferous dykes. The Blue Tier tin-field¹⁹¹ in the county of Dorset in the north-eastern part of Tasmania lies on the granitic compound batholith of Devonian age. The tin occurs in a special type of porphyritic granite. Tin also occurs associated with wolfram in the Avoca district¹⁸¹.

In the Stanley River tin-field the tin lodes are closely associated with acid igneous rocks, and the ore-bodies occur near the junction of intrusive Devonian granite with older (pre-Silurian or Silurian) sedimentary rocks, partly occurring in the igneous and partly in the sedimentary rocks, or in quartz-tourmaline veins in the granite.

The tin ores of the Heemskirk district⁵¹ occur also in close association with acid igneous intrusions, but the deposits are of several types, and the lodes are almost always marked by the occurrence of pyrites and of small amounts of ores of bismuth, molybdenum, and tungsten.

There are also many alluvial deposits of cassiterite in the country.

In **New South Wales** the chief tin-bearing areas are in Inverell and Emmaville districts. The lodes comprise fissures, joint- and pipe-veins. Most of them occur in the marginal belt of a huge mass of intrusive granite forming well-marked bosses in contact with clay-slates and shales. The veins consist of quartz, tinstone, and the usual associated minerals. Stockworks and impregnations also occur, and the pipe-veins are a special feature.

In **Queensland** the most important tin-fields are the Herberton and Chillagoe. The ore-deposits also include copper, silver, lead, wolfram, bismuth, antimony, etc. In the first-mentioned field intrusive hornblende-granite-porphry and quartz-felsite pierce the much folded greywackes, quartzites, and shales of the Gympie

formation and profoundly alter them, and are themselves intersected by large elvans and dykes of altered basic rocks. The latter are the chief matrix of the tin amongst the igneous rocks, but amongst the sedimentaries the lodes send off huge ' carbonas ' of tin and copper ore along the bedding-planes, or the tin may impregnate the sandstones. The ' deep leads ' of Southern Queensland and New England are in places stanniferous.

Superficial and alluvial deposits with detrital tin occur also in various parts of the State.

In the **Northern Territory**²⁸⁶ most of the tin deposits which are worked are alluvial, but tin-bearing dykes of pegmatite are also known.

In **Western Australia**²⁶ the alluvial deposits (of two dates) in the Greenbushes field in the south-west part of the State are the most important, but there are also primary deposits in the Wodgina field in the Pilbara district, where stanniferous pegmatite dykes traverse hornblende-schists, and carry tantalite and radio-active minerals in addition to the tin.

Copper.—The copper deposits of Wallaroo and Moonta⁵⁷ or Spencer Gulf in **South Australia**³²¹ consist of large lenticular masses of quartz, copper pyrites, iron pyrites, etc., enclosed in Pre-Cambrian intrusions of felspar-porphyry, either massive or schistose, and associated with granite and pegmatites.

The Burra Burra mines, north of Adelaide, have oxidation ores (carbonates of copper, etc.), down to about 300 ft., and then chalcocopyrite. The lodes are in a complex of slates, limestones, and sandstones of the Adelaide Series of Pre-Cambrian age.

The copper deposits of Pernatty Lagoon, west of Lake Torrens, are of special interest because they consist of impregnations of horizontally bedded sandstones. The ores themselves consist of atacamite, covellite, bornite, and chalcocite.

In the **Northern Territory**²⁸⁶ there are considerable deposits of copper in fissure-lodes and shear-zones in the metamorphic rocks.

In **Western Australia** the Whim Well copper mine, in the West Pilbara Gold-field, has the ore-deposit forming a very flat-lying lode conformable to the bedding of the enclosed weathered Pre-Cambrian talcose schists which strike north-west and south-east.

In **Queensland**³¹⁹ the Cloncurry copper-field contains ore-deposits consisting either of rich interstratified lenticular bodies, or impregnations of crush-zones or of bands of country-rock. The area consists of highly-inclined slates, quartzites, and greywackes, with occasional beds of limestones. Probably the copper of both the

Cloncurry and Mount Elliott fields is due to a Pre-Cambrian intrusion. The Mount Morgan mine is now one of the principal copper-producers, the siliceous sulphidic copper ore being worked below the oxidised zone (see 'Gold').

In **New South Wales** the Cobar field lies on fossiliferous Silurian or pre-Silurian sedimentary rocks thrust over Devonian rocks on the west. There are no igneous rocks, except two small intrusions of orthoclase-porphry, and the ore-deposits occur as interbedded veins or lenses up to 100 ft. in width, or as fissure veins. The pyrrhotite-chalcopryrite veins have no definite walls, but the pyritic veins, which also contain galena and zinc-blende, are more clearly limited and are generally younger than the other veins. The copper ore contains a variable amount of gold. The mineralisation may be of post-Devonian age.

In **Tasmania**²⁴⁸ the Mount Lyell copper-field^{5b 62} is the most important. The rocks consist of schists resulting from the intense alteration of quartz-porphyrates and of acid volcanic tuffs, together with masses of diabase-porphryite, frequently foliated and converted into quartz-chlorite-schists. The ores occur either (*a*) as fahlbands or long belts of mineralised schists, which are best developed near great transverse faults ; or (*b*) as huge thick masses of ore, chiefly occurring near the crossing of the transverse and overthrust faults and the thrust-planes. The ore is chiefly iron pyrites containing quartz, chalcopryrite, and some gold and silver, and in places it is highly siliceous ; or it may consist of pure bornite. Overlying the schists are conglomerates and quartzites, the latter being sometimes pyritiferous.

Silver, Lead, and Zinc.—The most important mines for these minerals in Australia are situated in the Broken Hill district^{1113 222 242 281 304 340} of the Barrier Range in **New South Wales**^{5b 12 13 65 140}. Here the rocks consist of highly altered slates, conglomerates, quartzites, sandstones, and limestones without any trace of organic remains. Frequently some of these are represented by micaceous schists or gneisses, and they are all intruded by bosses and dykes of coarse granite, and by dykes of felsite, pegmatite, diorite, and amphibolite. All the rocks have been much crumpled and contorted, but in Broken Hill itself they form an anticline, the axis of which corresponds with the crown of the range (about 2½ miles long), which is here composed of crystalline gneisses, banded quartzites, micaceous and hornblendic schists, and garnetiferous sandstones. The lode⁸⁰⁰ occupies the saddle-shaped cavity at the top of the arch. The cap of the lode is formed of manganiferous ironstone. The gangue consists of rhodonite, quartz, garnet, and calcite with some accessory minerals, and the sulphide ore is composed of an

Tertiary and Cretaceous basin
 with underlying Jurassic, and a few
 inches of Archaean and Palaeozoic.

II

Narrow
 Coastal
 Belt of
 faulted
 Mesozoic.

W.

F. F.

FIG. 22.—DIAGRAMMATIC SECTION ACROSS AUSTRALIA.

intimate mixture of galena and zinc-blende, both carrying a proportion of silver. Below the oxidised zone (containing carbonate of lead, kaolin, and ores of silver and native silver) come the massive unaltered sulphide ores, composed of mixed sulphides of lead and zinc, with a high silver content³⁰⁰. The lode^{243 304} has been generally regarded as an interbedded saddle-lode of enormous size, but Gregory believes that it is a vertical lode formed along a fault-plane. According to Kenny^{242 243} the main lode-channel * occupies a narrow zone of strong shear with differential displacement of the contiguous beds of sillimanite-gneiss^{>242}. The western and eastern ore-bodies which lie on opposite sides of the main lode are respectively anticlinal and synclinal in form, the shear zone representing the line of rupture of the limb connecting them. Drag-folds and minor movements have complicated the structure. A true fissure lode occurs close to this main lode, and cuts across the gneiss, schists, and other rocks, but its gangue is chalybite, and much of the silver in it is in combination with antimony. The Yerranderie Silver-field¹¹² has the lodes occurring in Devonian rocks and in post-Devonian igneous intrusions.

In **Tasmania**²⁴⁸ silver-lead ores of importance occur in the Waratah¹⁷⁹, Zeehan, and Dundas¹⁸³ fields. Here the Pre-Cambrian porphyroids (=keratophyres) with tuffs and breccias, which are often schistose, and basic lava-flows (spilites) are associated with slates or sandstones. Overlying them unconformably is the 'West Coast Range conglomerate' and Tubicolar Sandstone, and fossiliferous Silurian bed follow upon these. Devonian gabbro, amphibolite, serpentine, and granite intrude all these rocks. There are three types of veins, all **genetically**

REFERENCES

B. Bathurst.
 B.H. Broken Hill.
 Bg. Bingara.
 B.R. Bogan River.
 C. Caria.
 Cn. Coler.
 C.R. Clarence River.
 Cu.R. Culgoa River.
 D.K. Darling River.
 G. Gulong.
 Go. Goulburn.
 Gr. Grafton.
 Gw.R. Gwydir River.
 H.R. Hawkesbury River.
 Hu.R. Hunter River.
 I. Illawarra.
 In. Inverell.
 J.B. Jervis Bay.
 Ko. Mount Kosciusko.
 L. Lithgow.
 Lm. Lismore.
 L.R. Lachlan River.
 M. Maitland.
 M.R. Murray River.
 Ma.R. Macintyre River.
 Mo.R. Macquarie River.
 Mu.R. Murrumbidgee River.
 N. Newcastle.
 O. Orange.
 P.M. Port Macquarie.
 S. Sydney.
 S.R. Shoalhaven River.
 T. Tallong.
 Tm. Tamworth.
 T.R. Talbragar River.
 U. Ulladulla.
 W. Wilcannia.
 W.C. White Cliffs.
 W.R. Warrego River.
 Y. Yass.

Explanation.

	<i>Tertiary and Post-Tertiary.</i>
	<i>Upper Cretaceous (with some Post-Tertiary.)</i>
	<i>Jurassic.</i>
	<i>Trias.</i>
	<i>Coal Measures of Upper Marine Series.</i>
	<i>Lower Marine Series.</i>
	<i>Carboniferous.</i>
	<i>Devonian.</i>
	<i>Silurian (probably including some Ordovician.)</i>
	<i>Ordovician.</i>
	<i>Cambrian.</i>
	<i>Pre-Cambrian.</i>
	<i>Granites, etc. of various ages.</i>
	<i>Basalts and Andesites (chiefly Tertiary.)</i>

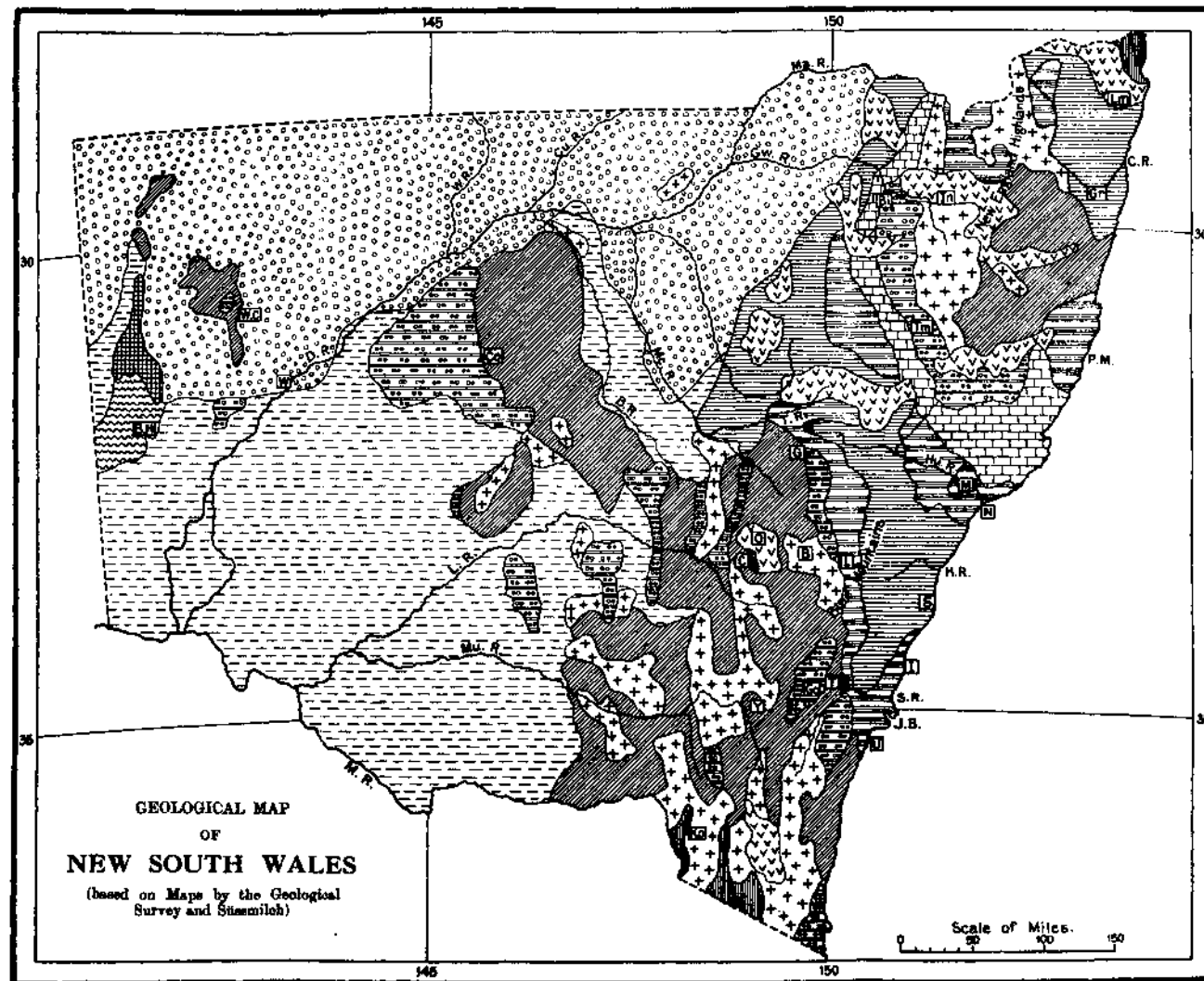


FIG. 23

connected, and all are fissure veins; they are known as the magnetite-bearing type, the galena-bearing type, and the stannite-bearing type. The galena type is pyritic and the lead is associated with blende and pyrites or siderite in varying proportions.

The Read-Rosebery district⁴⁷ on the west coast has the ore-deposits genetically connected likewise with the Devonian intrusive granite, and they occur in a zone of chloritic or calcareous schists in a series of bands of varying composition, one being chiefly of zinc-blende, another of galena, and another of pyrites. Their position has been determined by the original bedding or foliation planes of the schists, for they must be regarded as instances of metasomatic replacement.

Queensland.—The Mount Isa deposits^{103 170} in Queensland occur as lodes of silver-lead-zinc-ore of a metasomatic origin in a series of much-folded and sheared slates and quartzites of Pre-Cambrian age. The slates are altered and silicified or carbonated, and various sulphides¹⁰³ are associated with the sphalerite and galena. The chalcopyrite ore occurs outside the silver-lead bodies. No intrusive rocks are found near the mine.

The lead-zinc deposits of the other States of Australia are at present of less importance than the above.

Wolfram, Molybdenite, and Stibnite.—The chief deposits of these minerals are found in Queensland in the Chillagoe and Herberton districts, and elsewhere associated with the tin deposits. At Wolfram Camp the three ores are found in chutes or pipes in intrusive greisen close to its junction with slates. At Mount Carbine the wolfram occurs in a network of pegmatite dykes intrusive in slates near granite. Wolfram and tin occur in post-Permian but pre-Triassic intrusive granites on the New England plateau of New South Wales. In Tasmania wolfram and tin occur in the Avoca¹⁸¹ district.

Scheelite is worked at Hillgrove and Torrington in **New South Wales**, where it occurs, associated with stibnite, in auriferous quartz-reefs in an intrusive granite near its junction with slate.

Magnesite occurs in veins in serpentine at Bulong, Western Australia, and in many other places³³⁹.

Manganese.—There are deposits of manganese in Western Australia, near Mount Stuart in the Ashburton district, associated with haematite quartzites. There are also deposits at Yalgoo and **Phillip's River**. In the Brisbane schists in the Gladstone district in Queensland¹¹⁸ the mineral occurs as lodes of considerable size.

Osmiridium, Platinum, and Chromium.—These minerals occur in connection with intrusive serpentines. Osmiridium and platinum occur also as detrital ores, as in the Adamsfield district of Tasmania^{192 248}, and in beach sands in New South Wales and Queensland. The source is the Great Serpentine Belt of eastern Australia.

Iron.—The most important iron-ore deposits in **New South Wales**¹¹⁸ are the iron-ore beds of Carcoar and Cadia. At the latter place Ordovician graptolitic slates, shales, argillaceous sandstones and breccias, which are much folded and contorted, have sheets of andesite interstratified with them, and these enclose or have intercalated between them beds of iron-ore consisting chiefly of haematite, with a small admixture of limonite and more or less manganese, copper, and sulphur. The andesites themselves are highly altered.

In **Queensland** Mount Leviathan contains masses of pure specular or magnetic iron-ore in metamorphic rocks, and the formation and ore in the Kangaroo Hills and on Iron Island are somewhat similar. There are important ironstone-schists with haematite and magnetite in the Claude River district of Cape York¹⁴⁰.

In **South Australia**, at the Iron Knob¹⁸⁰ and Iron Monarch mines, near Port Augusta on Spencer's Gulf, there are huge deposits of iron, the lode extending at least a mile in length, and consisting of high-grade ore (haematite). These are of the age of the Mosquito Series.

At Olary, on the railway line from Adelaide to Broken Hill, there is a considerable deposit of uranium-bearing titaniferous iron-ore, now being worked for radium.

In **Western Australia**⁵² the Murohison district possesses banded haematite- and magnetite-bearing quartz-schists, with occasional masses or lodes of nearly pure haematite of great extent, as in the Weld Range and Yampi Sound near Derby and Mount Gibson.

In **Tasmania**²⁴⁸ ironstone deposits occur in the sandstones and quartzites of the Dial Range, over a large area. The Blythe River iron-ore deposit on the north coast consists of a huge vertical bed or lens of haematite having a north-east and south-west strike for a distance of over a mile, and apparently interbedded with pre-Silurian slates and sandstones. In the Beaconsfield and Salisbury districts the iron-ore occurs as haematite and magnetite partly in the serpentine (which also contains chromite) and partly in the adjacent sandstones which the serpentine invades.

In the Jukes-Darwin area the magnetite and haematite ores appear to be connected with the intrusion of the **Cambro-Ordovician** porphyroids.

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 A.L. Arnhem Land.
 A.R. Ashburton River.
 B. Brisbane.
 Ba. Ballarat.
 B.H. Broken Hill.
 B.M. Blue Mountains.
 Ck. Cooktown.
 Co. Collie.
 C.O. Cape Otway.
 C.R. Cooper River.
 C.Y. Cape York.
 D.R. Darling River.
 E.B. Eucla Basin.
 F.R. Fitzroy River.
 G. Gingin.
 G.A.B. Great Australian Bight.
 G.C. Gulf of Carpentaria.
 G.R. Gascoyne River.
 K. Kalgoorlie.
 K.D. Kimberley District.
 Ko. Mount Kosciusko.
 K.I. Kangaroo Islands.
 L. Launceston.
 L.C. Leigh Creek.
 L.E. Lake Eyre.
 L.G. Lake Gardner.
 L.M. Lake Macdonald.
 L.R. Lachlan River.
 L.T. Lake Torrens.
 M. Melbourne.
 Ma. Maryborough.
 M.D.R. Macdonnell Ranges.
 M.G. Mount Gambier.
 M.I. Melville Island.
 M.L.R. Mount Lofty Range.
 M.R. Murray River.
 Mu.R. Murrumbidgee River.
 Mu.Rg. Musgrave Ranges.
 N. Newcastle.
 N.P. Nullarbor Plain.
 Nu. Nullagine.
 P. Perth.
 P.D. Port Darwin.
 Pi. Pilbara.
 R. Rockhampton.
 S. Sydney.
 S.B. Shark Bay.
 S.G. Spencer Gulf.
 S.L. Salt Lakes.
 T. Townville.
 Ta. Tasmania.
 V.G. St. Vincent's Gulf.
 Y. Yass.

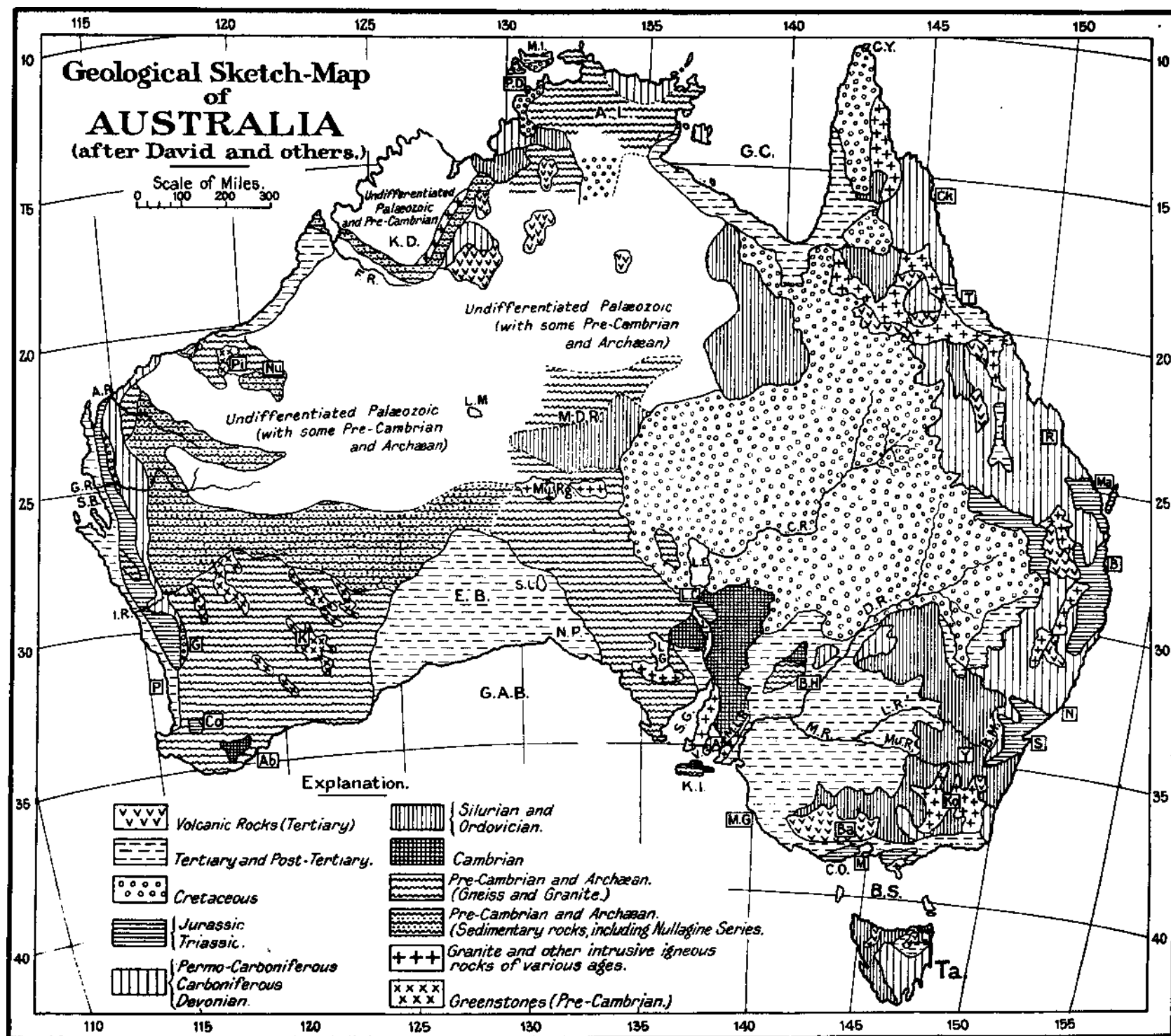


FIG. 24

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CHAPTER XIV

NEW ZEALAND

General Characters and Relations.—The three islands of New Zealand^{1 2} are situated on a large submarine plateau extending a variable distance from the present coast-line, but on the south-east they lie nearly on its edge. Whereas the depth of the water on the plateau is only between 300 and 600 fathoms, the surrounding ocean descends to a depth of 2000-3000 fathoms. In the North Island the north-west peninsula is extended in this direction by the 500-fathom line, and by way of New Caledonia and New Guinea appears to connect with the Malaysian arc, while the north-east peninsula is continued in a north-east direction along the edge of the submarine plateau so as to connect with the Kermadec and Tonga Islands. New Zealand¹³⁹ lies in fact at the southern end of the Tonga ridge on the south-east side of which there is a trench which includes the Tonga and Kermadec deeps in which the bottom lies over 30,000 ft. below sea-level. The ridge and trench appear to represent a great asymmetrical anticline, the western wall of the trench forming its east wing and the ridge forming the crest.

The geographical structure of New Zealand^{61 62} is dominated by two series of lines at right angles to each other, and these are intimately connected with the direction of the principal faults and fold-axes. The main series of lines is that running from the north-east to south-west^{38 62}, giving the long parallel east-and-west coast-lines of the South Island, and determining the course of its main mountain axes, while in the North Island the same lines are exhibited in the Wellington and Cook Peninsula and in the north-east promontory as well as in the general direction of the mountains parallel to the east coast.

The second set of lines running from north-west to south-east has determined the Auckland Peninsula, the old mountain axes of Coromandel and the Thames Peninsula, the transverse course of Cook Strait and the separation of the highlands of Otago from the plains of Canterbury. The relations of the North to the South Island and the formation of Cook Strait have been explained by two main hypotheses, *i.e.* (1) vertical block-faulting, and (2) lateral displacement. According to King's theory⁷² the western mountains in both islands were first uplifted, then the eastern mountains. Lateral displacement followed, the South Island moving west

faster than the North Island along a line of dislocation obliquely transverse to their trend. This movement, which disconnected the mountain ranges, took place in two stages, and was accompanied or followed by overthrusting and faulting. All these movements are supposed to have taken place in late Pliocene times¹³⁴.

The two chief systems of faults as well as the lines of folding follow the longitudinal and transverse directions, the system trending north-east and south-west being parallel to the longer lines of elevation, and in places determining the course of the coast-line. The Hauraki Gulf is a rift-valley determined by faults. Some of these principal faults along the western margin of the main mountain range in the South Island are overthrusts, and date from the chief period of the folding of the New Zealand Alps. A great fault traceable for 400 miles forms the north-west boundary of the Southern Alps sub-parallel to the coastline, though not defining the present¹³¹ margin of the land. A third minor set of faults in Central and Western Otago runs nearly north and south. The structural, stratigraphical, and palæontological relations of New Zealand with New Caledonia are remarkable, particularly in the Triassic faunas¹³⁰. King¹³⁴ has pointed out that the great New Caledonia submarine ridge enters the North Island along the North Auckland peninsula, while the Kermadec-Tonga ridge enters it by the East Cape.

General Distribution of the Geological Formations^{1-4 55 58 61 125}.—

Apart from the vexed question of the classification and age of many of the metamorphic rocks, the distribution of the strata is broadly as follows :—In the south-west of Otago and in Stewart Island, there are highly contorted gneisses and schists with certain plutonic rocks which are believed by some geologists to be the oldest in the islands. From Fiordland¹⁵² a series of crystalline schists and various metamorphic and igneous rocks stretches in a general northerly direction, forming the core of the main divide. Unaltered sedimentary beds, which are in many cases apparently inseparable from the same metamorphic series and seem to pass into them by gradual transition, cover a large area between the schists and the old gneisses of the south-west region, and form a wide band on the south-east side of the main divide up to the north-east corner of the South Island. These beds are arranged in a series of deeply-dissected folds. On the north side of the Cook Strait the same formations are continued into the North Island, constituting the main chain, (Ruahine Range) near the east coast, and they also occur in the core of the north-west promontory.

The age and classification of the beds of this complex and widely extended group of mostly unfossiliferous rocks are still matters of

controversy⁵⁸, and in places it has been definitely established that they are of various ages. Marshall¹ groups them all together under the name 'Maitai System.' Trechmann⁵ restricts this name to the Permo-Carboniferous rocks which have been proved by their fossil contents to be of this age. Various names have been given to the local developments of the complex series of mostly metamorphosed rocks; for example, on the west side of the Southern Alps the names 'Arahura Series' and 'Greenland Schists'^{23 38 42} have been applied to them in certain areas. Intrusive granites (the Tuhua Formation)⁴² and ultrabasic rocks (the Pounamu Series)⁴² occur associated with them. Park² recognises several separate groups of beds amongst these metamorphosed or unfossiliferous rocks, and refers them to the successive European Palaeozoic or Mesozoic Systems. Thomson¹⁸, on the strength of some scanty fossil evidence of their age, put them all into his second group of formations, which is mainly Mesozoic, his first group embracing the undoubted early Palaeozoic fossiliferous rocks, which have only a very small and local development at the extreme north and south extremities of the South Island (see below). It has been established that Ordovician, Siluro-Devonian, and Permo-Carboniferous rocks have also been locally involved in the folds of the South Island, for there is definite palæontological evidence of their presence, but no rocks of these ages are yet known for certain in the North Island.

After the deposition of all these beds the chief orogenic disturbance and folding of the islands took place, accompanied by the extensive metamorphism of the older rocks and the determination of the main structural lines of New Zealand. This is the great 'post-Maitai period of deformation'¹³⁹. According to Henderson, as quoted by Benson⁵⁸, the Palaeozoic rocks of the west coast of the South Island have been subjected to two series of foldings, the one producing north-east strikes over a long belt of country from Reef ton to Separation Point, the other affecting the rocks westward of this zone and producing north-west strikes; neither of these corresponds with the trend of the folds of the Alpine chain. The original fold mountains of the post-Maitai revolution were more or less completely destroyed by denudation before they were covered up by later deposits. The period of denudation which succeeded the post-Maitai period of deformation was followed by depression, and another group of formations was then deposited, comprising beds of Mesozoic and Tertiary age. This group has had the comprehensive new name 'Notocene' applied to it by Thomson⁴⁹. The lower part of it has an extensive development in the North Island, forming a wide belt practically all along the east coast; it is also exposed on the west side of the older rocks over the centre of the island, as far as the west coast and along the north-west

promontory, except where covered by volcanic or other rocks of later date. The beds are mostly of marine origin and fossiliferous, but some outpouring of andesitic lavas began before the close of the period. In the South Island these Notocene beds occur as a band of variable width all down the east coast and on parts of the west coast also with a fresh-water or terrestrial facies. In early Cretaceous times there was further folding of various degrees of intensity, and the axes had not all the same strike. According to Park these post-Jurassic pre-Albian orogenic movements (the *Eangitatan*) originated the north-east-south-west axial chain of New Zealand.

The upper part of the Tertiary Series, commonly known as the Wanganui System and referred to the Pliocene, is particularly well developed in the North Island as a series of important marine deposits on both the east and west coasts, but in the South Island the latter part of this period seems to have been marked by elevation and extensive block-faulting^{29 139}, accompanied by the accumulation of unfossiliferous or lacustrine gravels. This is sometimes called the Kaikouran, or Ruahine, Period of deformation. In addition to block-faulting there was crustal warping and overfolding in some areas. The chief system of longitudinal faults, as well as the warping, runs obliquely across the earlier lines of folding. It is this group of movements of Pliocene or Pleistocene age which has largely determined the present surface features of the islands. Vulcanicity took place on a large scale in the North Island⁵⁵ throughout Tertiary times, and has continued almost without intermission to the present day ; but it was much less widespread and of shorter duration in the South Island. The movements were intermittent, and the uplift and depression of the blocks by the faulting were unequal and differential. The above-mentioned movements of elevation, which generally set in over the whole area in late Tertiary times about the close of the Wanganui Period, reached a maximum in the South Island, and culminated there in widespread glaciation, resulting in the accumulation of much morainic material which was spread far out from the base of the mountains. Submergence to a slight extent then set in, depressing the land below its present level, but this was followed by an upward movement, of which the raised beaches are evidence, and it is locally still in progress.

Palaeontology.—Chapman's book on *Australasian Fossils*⁵⁴, above mentioned in connection with Australia, may be usefully consulted for references to New Zealand fossils.

DETAILS OF STRATIGRAPHY

Classification of the Formations.—The classification of the formations in New Zealand is in a somewhat unsettled state, and no generally accepted correlation of the various local developments or their equivalence with European

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stages or series exists at present. But the main stratigraphical divisions can be recognised, though their subdivisions do not precisely agree with the European scale. There is a closer correspondence with the Australian scale. The following European systems or formations have been satisfactorily recognised, but there are many of the smaller series or stages in New Zealand which have not been precisely correlated. The local names are given in the following descriptions, and their probable equivalent European horizons are mentioned.

Pleistocene	}	
Pliocene		
Miocene		
Oligocene		
Eocene		
		Danian (?) (<i>Wangaloan</i>).
Cretaceous	}	Senonian (<i>Piripauan</i>).
		Cenomanian (<i>Clarentiari</i>).
Trias ³⁷	}	often included in the Maitai System.
Permian ⁵	}	(' Permo-Carboniferous ') (<i>Maitai System</i> ¹³⁶ (<i>pars.</i>)).
(?) Carboniferous		(not clearly recognised).
Devonian ^{68 71}		(<i>Baton River System</i>).
(?) Silurian		(doubtfully represented).
Ordovician ¹¹⁷		(<i>Aorere System</i>).
(?) Cambrian	}	(not proved to be present). (<i>manapouri System</i>).

The Silurian and Cambrian formations have not been proved to be present by palæontological evidence, and the existence of Carboniferous beds is doubtful.

MANAPOURI SYSTEM (Archaean or Pre-Cambrian)

South Island.—The whole fiord-region of the south-west corner of the South Island is largely occupied by this formation, which consists of gneisses of various types^{76 97 98} (especially diorite-gneiss) and granulites, with some plutonic intrusives. The rocks are foliated, and the plane of foliation usually dips to the north-west. Schists of various kinds and marble (as in Milford Sound) are also known.

The true relations of this crystalline complex with the neighbouring rocks are not determined beyond dispute⁵⁸; the junction is supposed to be marked by a fault, but intrusive granites of supposed later age complicate the structure.

Whether any of the metamorphic rocks¹¹⁶ and crystalline schists, such as those of Eastern Otago¹¹⁸ or the Greenland Series^{28 38 42} (see below), or some of the intrusives, such as the Tuhua granites and their associated igneous rocks, and the Pounamu⁴² ultrabasic rocks of the Hokitika area which invade the schists and alter them, are of Archaean or much later age, is an open question. Probably many of them belong to later systems.

AORERE SYSTEM (Ordovician)¹¹⁷

Near the West Wanganui inlet in the Nelson area at the north-west end of the South Island, shales have been found yielding graptolites^{18 26 66 78} which include well-known European species of *Bryograptus*, *Dichograptus*, *Didymograptus*, *Phyllograptus*, *Tetragraptus*, etc.¹³. The nomenclature of the

various stratigraphical divisions of the Ordovician in north-west Nelson now adopted⁷⁸ is the same as that employed in Victoria, Australia. The lowest series corresponds to the *Lancefieldtan*, the next is the *Bendigonian*, and the following is the *Castlemainian*, of which there are three subdivisions containing a very large assemblage of graptolites⁶⁶, all of which belong to the Lower Ordovician, and are developed in the Aorangi Mine⁷⁸ area. Some phyllocarids have also been described from these beds, as well as the graptolites. In the Mount Arthur area⁷⁸ Lower Ordovician beds, likewise graptolitic, are present. The Ordovician Gisborne Series in north-west Nelson⁷⁸ comprises Middle and Upper Ordovician beds marked by other graptolites, and probably the two trilobites, *Ogygites collingwoodensis*^{63 77} and *Dionide hectori*^{63 77}, came from this series of beds. In Preservation Inlet⁷⁰, in Fiordland on the south-west coast of the South Island, there is also a series of Lower Ordovician beds belonging to the same three divisions and containing abundant typical graptolites, together with a few brachiopods, phyllocarids, and sponges. As these sedimentary beds are followed eastward they become metamorphosed into schists, and intrusive granite has also produced contact-alteration.

It has been maintained that the bulk of the older sedimentary rocks west of the Alpine Range in Nelson and North Westland, including the 'Greenland Series,' is of Ordovician or Siluro-Ordovician age⁶¹. But the evidence is hardly sufficient for this important conclusion²⁵, for fossils are wanting. In the south-west Fiordland^{100 152} Benson⁷⁰ maintains that some of the metamorphic rocks are altered Lower Ordovician beds, resulting from intensive earth-movements and the intrusion of various plutonic masses (granites, granodiorite, and norite) and dykes of many types⁷⁰. The date of their intrusion is a matter of uncertainty, and may be late Palæozoic or even Mesozoic.

BATON RIVER SYSTEM (Lower Devonian)

A bluish argillaceous limestone occurs on the Baton River⁶⁸, Nelson, and contains many fossils, amongst which have been identified many brachiopods, including *Spirifer* (*Eospirifer*) *togatus*, *Orihis* (*Schizophoria*) *provulvaria*, *O. (Hipparionyx) minor*, etc. The fauna is typically north European in character, and has nothing in common with the Austral faunas of South Africa and South America, according to Shirley⁶⁸. These beds, which were formerly referred to the Silurian¹⁸, are said to be conformable to bituminous schists which are supposed to belong to the top of the Aorere System, but the relations are somewhat uncertain.

At Reefton⁷¹, 70 miles distant, the assemblage of fossils is slightly different. The brachiopods include *Spirifer* (*Acrospirifer*) cf. *hercyniæ*, Sp. (A.) cf. *hystericus*, *Leptocoelia flabellites*, and species of *Eatonia*, *Camarotoechia*, and *Meganteris*, with a few lamellibranchs and species of *Homalonotus*. The whole fauna here also has a Lower Devonian boreal facies, according to Allan⁷¹, but there are noticeable features indicating affinity with the South African Lower Devonian (Bokkeveld) and South American faunas. The beds vary much in lithological character, and include argillites, greywackes, quartzites, sandstones, and even limestones. Hector rightly placed the beds in the Lower Devonian, which is confirmed by Allan⁷¹.

It has been thought that much of the schist area of the west coast, and even of Otago^{116 118}, may belong either to this or the Aorere System, but Marshall classes all these metamorphic beds with the Maitai.

MAITAI SYSTEM (in part) ('Permo-Carboniferous')

The strata succeeding the Devonian in New Zealand have no universally accepted classification, and the views regarding the age and correlation of these

widely-spread pre-Cretaceous beds are extremely divergent. Some geologists recognise Carboniferous (?) and Permian beds as forming part of the complex as well as Triassic and Jurassic, for the presence of beds belonging to all these systems is held to be proved by fossil evidence¹⁸, though no important widespread breaks in the series have been established, and the divisions instituted by some geologists have been largely based on lithological grounds. Moreover, great difficulties have been introduced by the metamorphism in many places which the beds have suffered owing to dynamic and contact processes, while the folding of the beds and tectonic disturbances which have frequently taken place on a great scale have introduced further complications, and different views on the age of all the rocks still prevail¹³⁶.

Marshall applied the name Maitai System to all the folded rocks of the South Island east of the Hope Pass and Reefton, and stated that no widespread unconformities have been detected in this immense series, and that no fossil evidence is available for its satisfactory subdivision. But this wide application of the name Maitai is not here followed, and Trechmann's⁵ limitation of it to the Permo-Carboniferous seems more satisfactory. There is a continuous outcrop of the so-called Maitai shales and greywackes from Nelson nearly to Kakanui, but shortly after Mount Cook is reached the south-west line of outcrop bends to the south-east, and thus stretches to the coast. In places on both sides of the Southern Alps a complete and gradual transition is stated to have been traced from these unaltered rocks into mica-schists, as in Otago¹¹⁶, but it is possible that some of the latter may be much older, as above stated. There is a great mass of intrusive rocks, chiefly hornblende-diorite, in the Clinton River district¹⁴⁷ lying between the Manapouri gneisses and schists to the west of Lake Te Anau, and the Permo-Carboniferous (?) (Maitai) argillites and greywackes on the east, and invading the latter. The date of the intrusion is uncertain.

Part of the Maitai System seems undoubtedly to belong to the **Upper Palaeozoic**¹³⁶. For instance, in the Wairoa Gorge, McKay recorded the occurrence of Carboniferous fossils, including *Spirifer bisulcatus*, *Sp. glaber*, *Productus brachythcerus*, etc., but the identification of the specimens has been questioned. Recently Trechmann⁵ has described from the same locality some species which occur in the 'Permo-Carboniferous' beds of Australia, including *Aphanaia* cf. *mitchelli* (= *Maitaia trechmanni* Marwick), *Martinia subradiata*, and other species. The limestone in which they occur is 1000-2000 ft. thick, and lies in a syncline faulted and thrust over Triassic beds. Recently¹²¹ at Clinton, in Otago, some poorly-preserved fossils, including brachiopods and a lamellibranch like *Aphanaia* (*Maitaia*) *trechmanni*, have been found below Triassic beds, and probably belong to the same formation. A boulder-bed or conglomerate, which is stated to resemble closely the Talchir boulder-bed of the Indian Gondwanas, is said to be present all the way from Southland to East Cape in Auckland², and has been claimed to be Permian in age.

TRIAS

Beds of **Triassic**³⁷¹¹⁹ age are proved by their fossil contents to occur in both the North and South Islands, as Trechmann³⁷ has shown. They consist³⁷ of coarse or fine felspathic sandstones, grey or dark shales and argillites, some hard, some splintery, and frequently enclosing concretions. There are also thick beds of coarse conglomerates at various horizons more or less lenticular in shape. The Rhætic beds are more pebbly and glauconitic and less felspathic. The whole series has a marine but littoral character, and ammonites and corals are rare or absent. The total thickness amounts to many thousand feet. Only the Rbeetic and Noric beds are known in the North Island; they

occur at Kawhia¹³¹ folded with Jurassic rocks, into which they pass up conformably. In the Mokau area, Taranaki¹⁴⁸, there are beds of Rhætic age containing plant-remains (*Cladophlebis*, *Teniopteris daintreei*, etc.), including the same species as in Australia, which is remarkable as the marine faunas are distinct. The beds consist of greywackes and sandstones which have been much disturbed and faulted by pre-Tertiary movements. In the South Island the Trias is found in the Nelson district much faulted and folded, but with a general strike parallel to the main structural axis. In the Okuku area (Ashley County) farther south, there are some limestones in addition to sandstones and conglomerates, the fossils of which suggest a Carnic or Noric age.

The Mount Potts Beds yield marine fossils in black argillites, and seem to be of early Upper or late Middle Trias. The plant-remains^{14 57} from this locality, however, indicate a Rhætic or Lower Jurassic age, and include several species of the Upper Gondwana flora of Australia, such as *Teniopteris daintreei*, *Thinnfeldia lancifolia*, *Cladophlebis australis*, *Dictyophyllum acutilobum*, and *Palissya conferta*. The beds at Mount St. Mary seem to be of approximately the same age (Ladino-Carnic) as the marine fossiliferous deposits of Mount Potts, and together with them form part of the eastern fringe of the complex Alpine chain, and are crushed and partly metamorphosed.

The Hokonui Hills¹⁹, and the ranges extending from them to Nugget Point at the south end of the island, contain all the divisions of the Trias-Rhætic Series, and are all fossiliferous. The conformably overlying Jurassic also contains abundant organic remains (see below). The beds are folded into an asymmetrical trough, in the northern limb of which the beds are vertical and form a great mass of greywackes and conglomerates belonging to the 'Kaihiku Series.' At Nugget Point⁶⁷ there is a clear section of the whole succession up to the Rhætic. Trechmann³⁷ has recognised as the lowest horizon the beds with *Paonella indica* forming the **Kaihiku Series**¹⁹, which he correlates with the Ladino-Carnic stage. The succeeding beds containing species of *Halobia*, *Myophoria*, and *Maoria* belong to the **Wairoa Series** of Carnic age. The Noric Stage is represented by beds with *Pinacoceras*, *Pseudomonotis*, and *Spiriferina* and *Clavigera*, constituting the **Otapiri Series**. These three series are divisible into successive horizons characterised by different fossils. According to Wilckens⁶⁴ the beds in the Wairoa district, Nelson, and near Nugget Point on the east coast of Otago⁶⁷, indicate chiefly a Carnic or Noric horizon, and the occurrence of *Halobia*, *Pseudomonotis ochotica*, and *Proclydonautilus* are also typically Upper Triassic. The Lower and Middle Trias do not seem to be represented here, but the Ladinic may be present. The Kai-koura Range in East Marlborough is composed of unfossiliferous greywackes, etc., of supposed Triassic age.

The fauna of the Triassic beds in New Zealand is poor in cephalopods, and none has been found in the Kaihiku Series; the same types which are wanting in New Caledonia and the Malay Archipelago are here also absent. The gastropods are of comparatively small importance, but the lamelli-branches are numerous and interesting, including *Pseudomonotis ochotica*, *Monotis salinaria*, *Daonella indica*, *Halobia zitteli*, and other Asiatic and European species. A shell known as *Mytilus* (?) (—*Maoria* Marwick) *prohmaticus* marks a constant horizon in the Carnic beds in the South Island, and also occurs in New Caledonia, while a new *Lima*-like genus called *Hokonuia* by Trechmann is represented by several species. The genus *Megalodon* and several species of *Myophoria* (previously identified as *Trigonia*) are noteworthy. The brachiopoda include the rhynchonellid genus *Hahrella* Bittner, the Palaeozoic genus *Dielasma*, and several genera of spiriferoid shells, including *Spiriferina*, *Cyrtina*, *Retzia*, *Mentzelia*, *Athyris*, and some new and peculiar

genera (*Mentzeliopsis* and *Heetoria*)³⁷. Although the general facies of the faunas is Triassic and includes several typical species and genera, yet there is a peculiar character of the New Zealand fauna, for it is devoid of any close affinity with that of other areas except that of New Caledonia, as Benson⁵⁹ 119 120 130 has pointed out.

JURASSIC

The **Jurassic** beds^{56 67}, which are chiefly sandstones and marls, and conformably overlie the Trias, are largely developed in the Hokonui Hills¹⁹, and have yielded species of ammonites (including several new genera), *Belemnites*, *Aucella*, *Ostrea*, *Pholadomya*, etc. The lowest Jurassic¹¹⁹ rocks (Bastion Series) are of Hettangian age and occur in the Hokonui Hills; they contain species of the genus *Psiloceras*, and higher Liassic beds are indicated by other ammonites.

In the North Island the beds containing the problematical fossil, presumably an annelid, named *Terebellina* (*Torlessia*), are found near or parallel to the east coast. (The same fossil occurs in beds of probably the same age in Canterbury in the South Island). In the Kawhia¹³¹ district on the west coast of the North Island Trechmann and Spath⁵⁶ describe beds of Bathonian and Callovian-Oxfordian age yielding many lamellibranchs with a few ammonites, gastropods, and brachiopods. The Jurassic of New Zealand agrees in general features with that of most other regions around the Pacific⁶², but is in striking contrast with that of eastern Australia and Tasmania⁵⁶. Uhlig and Marwick⁸⁰ emphasised the affinities of the New Zealand Jurassic fauna to the Indian, but Spath⁵⁶ believes that there is as much affinity in the case of the ammonites with those of the Alpine and South American regions⁶⁰. It is strange that there is no close relationship of the Jurassic fauna with that of New Caledonia as in the case of the Triassic⁶⁰. The New Zealand fauna seems comparable with that occurring in the East Indian Islands and Malay Archipelago in beds of this age. In the Coromandel area⁴³ fossiliferous Upper Jurassic or Lower Cretaceous beds have also been observed. The true upper limit of the Jurassic in New Zealand is an unsettled question, but Boehm³⁹ considered that certain ammonites and other mollusca from Kawhia indicated passage beds between the Jurassic and the Cretaceous⁵⁹, and Spath⁵⁶ has recorded Tithonian ammonites from several localities in New Zealand. The Belemnite beds of the Waikato Heads district¹⁶³ consist of shales and contain amongst many other lamellibranchs the species *Parallelodon egertonianum* (Stol.) of the Spiti Shales of India, east Africa, and southern Arabia. There are grounds for holding that, in Rhaetic and probably also in Jurassic times, New Zealand and Tasmania were united as land areas with Australia, judging from the flora⁵⁷ in these beds, but whether New Zealand formed part of Gondwanaland is a disputed point^{59 60}.

Igneous Rocks.—Contemporaneous igneous rocks are mostly absent from the whole series of formations covering the long period from the Permo-Carboniferous to the Cretaceous, but in the Coromandel area rhyolitic lavas and tuffs are interbedded with the Trias-Jurassic mudstones and greywackes on the east side of the Tokatea Range and in the Taranaki region¹⁴⁸, where andesites also occur. In the South Island Marshall ascribes to the Trias-Jura period the large series of volcanic rocks on the western margin of the Canterbury plain, from the Rangitata to the Waimakariri, and they include rhyolites, pitchstones, and andesites, while at Nelson and Orepuki melaphyres and tuffs are found, but these latter seem to have been erupted after the elevation and denudation of the Jurassic, according to Park.

The chief orogenic movements (the *Bangitatan*) which succeeded the long

period of sedimentation, lasting till the close of the Jurassic, culminated in Lower Cretaceous times, when the earlier Mesozoic and older rocks were much folded, broken up, and metamorphosed. The main axis was approximately meridional. Plutonic intrusions and the production of schistosity in some of the older rocks then took place. It has been suggested that the Otago schists may then have been formed^{61 118} from some of the Mesozoic rocks. Accompanying the great orogenic movements are masses of intrusive rocks, but some of these are of earlier or later date. Of these the granites of the Mount Radiant subdivision, Westport, are post-Aorere in age³⁵, while in the Hokitika area⁴² the complex of granites, granitites, and syenites, which, with later aplites and pegmatites, constitute the previously mentioned 'Tuhua Formation,' invade and alter the schists, phyllites, and other rocks known here as the 'Arahura Series'⁴². In the same region there are intrusive sills and sheets of dunite or allied olivine rocks, forming the already mentioned 'Pounamu Series'⁴², which are themselves altered by static metamorphism. The ultrabasic rocks (dunites, peridotites, etc.), especially at the north end of the South Island and at Mount Dun³⁴, which pierce metamorphic rocks ascribed to the Maitai System, may be of the same age as the Pounamu Series. In places these ultrabasic rocks carry copper and chromite. At the North Cape there are gabbros, norites, and harzburgites, which pierce rocks also referred to the Maitai System. There is much work still to be done in correlating and fixing the date of these various intrusions, and of the rocks which they traverse. In the Mount Somers district there are late Jurassic and late Cretaceous volcanics, according to Speight¹⁰⁹. It is possible that the Clinton River intrusives¹⁴⁷ in the Te Anau district of western Southland, which have been previously mentioned as intrusive into doubtful Maitai rocks, belong to this period of igneous activity. The ultrabasic rocks, pillow-lavas, and associated igneous rocks at the northernmost end of the North Island¹⁸⁶ may probably be ascribed to the pro-Cretaceous period.

CRETACEO-TERTIARY^{21 89}

The correlation and classification of the younger rock series in New Zealand¹⁶ is another matter of much difficulty, and there is little agreement and no uniformity of nomenclature^{65 85 89}. In the sense in which Marshall¹ used the term 'Oamaru System' it included beds of late Cretaceous and of Lower and Middle Tertiary age¹⁵. These beds are widely distributed, are usually horizontal, and rest with a marked unconformity on the older rocks, but they were believed themselves by Marshall to form an unbroken series^{15 16 18}. On the other hand, Morgan²¹ maintains the existence of several widespread unconformities amongst them, besides several local ones of minor importance. Park² used another classification and nomenclature. There is, however, the comprehensive name Notocene proposed by Thomson⁴⁹ and used by Benson⁶¹ for all the rocks lying with marked unconformity on the Maitai Series, and reaching up to, but not including, the Raised beaches—that is, all the rocks between the post-Maitai and Kaikoura deformations. The terms employed by Finlay and Marwick⁸⁹ in the nomenclature and classification of the beds are here adopted with some slight modifications.

Economically the whole series is of considerable importance, since it includes valuable coal-seams.

A considerable variety of types of development occurs in the North and South Islands, and many palaeontological horizons of widely different age are recognised. But the outcrops are frequently isolated, and the beds, which are locally much disturbed, change in lithological character from place to place, so that correlation is difficult. It has been suggested that these irregularities and variations were caused by the overlap of formations on a subsiding uneven

floor which also was unequally depressed at different times in different areas. Another hypothesis is that block-faulting and tilting of the crust went on at intervals during the deposition of the beds and were accompanied by erosion, so that locally unconformity and apparent conformity may exist side by side in the same area. The correlation of the Cretaceous and Tertiary beds with the European succession is rendered more difficult and confusing owing to the multitude of new and peculiar molluscan genera which have been recognised in the New Zealand faunas, especially in the Tertiary Series. For they belong to a distinct zoogeographical province.

(a) **Cretaceous** (Amuri System of Park²).—Cretaceous fossils^{6 7 80 115 133} are found in the provinces of Canterbury and Marlborough at various places between the Malvern Hills (west of Christchurch and Coverham in the Clarence Valley), and two well-marked horizons have been proved. The older beds have a fauna which resembles that of the Lower Utatur Beds (Cenomanian) of southern India and of the Indo-Pacific region generally. At the base of the Cretaceous Series are conglomerates followed by sandstones, mudstones, and limestones, which, in the Clarence Valley¹⁶¹, have a total thickness estimated at over 10,000 ft. Volcanic rocks are associated with them. This series has been named the *Chrentian*. *Gaudryceras sacya* and *Turrilites circumtceniatu* Sy both occurring in the Lower Utatur Beds, as well as *Inoceramus concentricus*, and species of *Behmmites*, *Trigonia*, and *Aucellina*, have been found in these beds.

The higher Cretaceous beds are of Senonian age, and are found at Amuri Bluff and at other places farther south, including Weka Pass^{16 45 112} and the Malvern Hills. These beds have been termed the *Piripauan*¹¹². The fauna has likewise an Indo-Pacific faunas, and though most of the species are peculiar the affinities are with those of the Trichinopoli and Ariyalur groups of southern India^{6 7 65 133}. There is also a strong South American element, several identical species being common and many others closely related^{59 62 65 79 80}. As Benson⁵⁹ and others have pointed out, there is strong affinity between the faunas of the Upper Cretaceous of New Zealand, New Caledonia^{120 130}, Graham Land, Patagonia¹⁶⁵, Chile, and Peru, and Wilckens^{79 133} concluded therefore that there was a coastal connection between New Zealand, Graham Land, and Patagonia at this period. Amongst the gastropods the genus *Pugnellus* (= *Conchothyra*) is particularly conspicuous.

At Amuri Bluff^{80 112}, where the best section of the Cretaceous is seen, a calcareous conglomerate near the base yields a rich fauna of lamellibranchs¹³³ and gastropods⁷⁹; the genera *Trigonia*, *Osirea*, *Pecien*, *Callista*, and *Astarte* are most abundant. Cephalopods¹¹⁵, which are rare, include species of *Kossmatiereras*, *Gaudryceras*, *Baculites*, *Hamitss*, and *Nautilus*. This bed is of Cenomanian (*CkireMiian*) age. An overlying series of greensands, 485-081 ft. thick, is remarkable for the number of reptilian remains belonging to species of *Cimoliosaurus*, *Liodon*, and *Platecarpus*, and this reptilian fauna is said to be very similar to that of the Niobrara Chalk in the United States. These greensands are correlated with the Campanian and Santonian (*Piripauan*). Above the greensands comes the so-called 'Amuri Limestone'^{20 24 129}, which is a pure Globigerina ooze, and is widely spread, occurring not only in Canterbury and Marlborough, but also in Wellington, Hawke's Bay, and Auckland. At Amuri Bluff it is estimated to have a thickness of 030 ft., and is a fine-grained chalky deposit with a few fish-remains; it also yields many mollusca of Tertiary aspect as well as foraminifera. Rounded flints and flint beds also occur in the Amuri Limestone²⁴ in places. It should be noted that Finlay⁸⁹ refers it to the Tertiary, and puts it in the Otatoran Stage of the Oamaruan, which is equivalent to the European Oligocene. Thomson^{118 181} would place the 'Weka Pass Stone' and the 'Amuri Limestone'¹²⁹ as high as

the Miocene (Oamaruan), while Allan refers the Weka Pass Stone to the Duntroonian Stage of that system. According to Marshall¹⁶ there is a complete conformable sequence of sediments at Amuri Bluff and the Waipara, the lowest beds containing Cretaceous fossils and the highest an Upper Miocene fauna, but Morgan²¹ (as stated) disputes this interpretation. Speight and Wild⁴⁵ maintain that there is stratigraphical conformity, and that there was no interruption in the deposition. According to Thomson²⁴ and Suter the fossils in the Amuri Limestone are Cretaceous at the base of the formation and Tertiary at the top.

In the Weka Pass district^{16 45 112} the beds are on the whole similar to those of Amuri Bluff. The lower part includes coal-seams, but the upper beds yield the marine fauna and the reptiles of the Amuri Bluff beds. Though there is generally a great difference between the faunas of the Upper Senonian (Piripauan) and lowest definitely Tertiary beds in New Zealand, yet there is one peculiar formation, the *Wangaloan*^{82 138}, in Otago, on the coast south-west of Dunedin, which has a curious mixture of faunas with a strong Cretaceous element^{81 82 85 89 138}, and it has been suggested that this stage should be correlated with the Danian, or Montian. But one-third of the molluscan genera are peculiar to it, and only nine out of the total of seventy-five are Cretaceous, while nineteen are Tertiary, with twenty-one common to both formations. Allan⁸⁵ remarks that 'the characteristic mollusca are almost entirely distinct from any that follow them in the Dominion.' The beds are calcareous glauconitic sandstones, and Allan puts them in the Kaitangatan System. Davies⁸⁷ regarded the fauna as Palæocene and as showing Californian and Patagonian¹⁶⁵ affinities. Finlay and Marwick^{82 89} suggest that the Wangaloan Stage, falling between the long period separating the Ma3strichtian from the Palæocene, may be either earlier or later than the Danian, or overlap both in part. No ammonites, belemnites, or *Inocerami* at any rate have been detected in it. So that on the whole we may put it as transitional. In this connection Marshall¹⁶⁰ has discussed the relations between the Cretaceous and Tertiary, not only in New Zealand, but in other countries.

In the Malvern Hills and other localities in the Canterbury province rhyolites rest on an eroded surface of Jurassic rocks and are followed by coal measures, often of great thickness, and these are succeeded by fossiliferous marine beds containing the fauna of the calcareous conglomerate (Cenomanian) of Amuri Bluff. Beds lithologically similar to the Saurian beds succeed them, but the Amuri Limestone itself is not present. At Rakaia Gorge and Mount Somers¹⁰⁹ in Canterbury, rhyolitic tuffs are interbedded with the coal-seams. It is probable that the basal rhyolites of Lyttelton Harbour in the Banks Peninsula^{102 132} are of the same age as these Cretaceous volcanics. In the North Island there are Upper Cretaceous beds in the Kaipara division on the Whangarei Bay of Islands^{123 168}. Senonian plant-remains are there found associated in beds with typical marine fossils.

The Kaitangata Upper and Lower Coal-Measures in Otago are also partly of Upper Cretaceous age⁵⁰ and are overlain by the Wangaloan beds⁸².

(b) **Tertiary** (Eocene-Miocene).—The classification and nomenclature of the Tertiary beds as given by Allan⁸⁵ recognised four main divisions thus in descending order :—

Wanganuian System	.	.	Pliocene.
Taranakian System	.	.	„ (in part).
Oamaruan System	.	‘	Miocene Oligocene.
Kaitangatan System (in part)			Eocene.

A large number of stages are present in each division, with much local

variation in character and bearing local names, but their correlation in different areas is a matter of dispute, and the names are unfortunately used with different significance by different geologists. Marwick⁸³ has given a useful synopsis of the various stage-names employed or suggested. The marine and non-marine stages have usually distinctive names, and their equivalence is often uncertain or disputed. The correlation of these systems and stages with the European divisions of the Tertiary can only be approximate, and has been discussed by Vaughan¹²⁴, for the diastrophic history of New Zealand does not agree with that of Europe. Finlay⁹⁴ has used the foraminifera^{86 150} as marking the successive stages and for determining the classification of the marine Tertiary beds, and Finlay and Marwick^{89 183} have given a list of the divisions recognised by them, with their typical mollusca, braehiopoda, and foraminifera, stating the type localities. The following are the successive stages in ascending order :—

<i>Middle Eocene</i>	Bortonian (Park).
<i>Upper Eocene</i>	Tahuian (Allan).
<i>Loner Oligocene</i> .	Kaiatan (Morgan).
<i>Middle Oligocene</i> ,	Whaingaroan (Finlay).
<i>Upper Oligocene</i> .	Waitakian (Park).
<i>Loner Miocene</i> .	Hutchinsonian (Thomson).
<i>Middle Miocene</i> .	Awamoan (Thomson).
<i>Upper Miocene</i> .	Tongaporutuan (Marwick).
	Urenuiian (Henderson).
<i>Lower Pliocene</i> .	Opoitian (Finlay).
	Waitotaran (Thomson).
<i>Middle Pliocene</i> .	Nukumaroan (Morgan).
<i>Upper Pliocene</i> .	Castlecliffian (Thomson).

It is pointed out that the stages are not all of equal value, and that the faunal gaps are often only of facial or local importance. The above correlation with European divisions can only be regarded as provisional. The development of the Tertiary is much more complete and varied in the South Island than in the North Island, where, however, the Pliocene beds are mostly found and are strongly represented. There is a fresh-water and a marine facies in many cases. The oldest, according to Park and Thomson⁴⁹, are the Paparoan coal-beds of North Westland (see below). These and other bituminous coal-beds are succeeded by the brown coal-beds or measures, and the latter occur at the base of the so-called Oamaru Series, which is typically marine in character. Practically all the mollusca belong to genera and species peculiar to the Tertiary of New Zealand.

It appears that owing to overlap we sometimes find the fossiliferous Tertiary resting directly on the old basement rocks, but in other cases it is the Cretaceous which occupies this position, and the sequence is not everywhere complete. The successive overlap of the beds points to a continuous depression taking place during sedimentation¹⁵. It is moreover recognised that the coals of New Zealand are associated with several different molluscan faunas, and therefore must reasonably be regarded as belonging to more than one stratigraphical horizon, and as terrestrial or fresh-water representatives of various marine strata in other parts ; some, as above mentioned, are of Cretaceous age.

Eocene.—The oldest marine formation of definitely Tertiary age is that termed the *Bortonian*^{80 82 89} in the Waitaki Valley near Oamaru. This stage may probably be correlated with the Middle Eocene of Europe, and Allan^{85 88} has described the fauna occurring in the Waihao greensands of this age.

The Eocene or Bituminous Coal-Measures²⁹¹⁴⁴, which are found only along the western coastal districts of the South Island, comprise great basal conglomerates or breccias, shales, grits, and micaceous sandstones as well as coal-seams, and, according to Hector, are 2300 ft. thick, but vary from place to place. Leaves of various dicotyledonous trees not now existing in New Zealand have been found fossil in the shales and sandstones, and include oak, elm, beech, myrtle, laurel, pine, zamias, and palms.

In the Greymouth and Buller-Mokihinui Subdivisions, North Westland²³ 29 IOOTHE-Measures (=Park's Lower or Waimangaroa Series²) are of great thickness, and are divided into the *Paparoa Beds* below, and the *Brunner Beds* above, the latter being overlain by marine fossiliferous sandstones or mudstones, in which the presence of *Aturia australis* and *Carcharodon angustidens* indicates an age 'not older than Upper Eocene,' according to Morgan²³. The Paparoa Beds are of a unique character, and in their typical development consist of a thick basal conglomerate which rests on the 'Greenland Series,' and is followed by a long succession of shales, sandstones, and coal-seams with a flora more allied to that of Shag Point⁵⁰ in Otago than to that of the Brunner Beds. Morgan suggests for them a Lower Eocene age. These fresh-water beds⁶⁵ underlie the marine Bortonian and are probably of Lower Eocene or partly Upper Cretaceous age⁸⁵. The Brunner Beds contain rather a different flora, but may also be of Eocene age. It is these Brunner Beds which are well represented in the Buller-Mokihinui and Westport-Seddonville districts, and contain many valuable coal-seams. In the former area marine mudstones, etc., with a scanty fauna, close the pre-Miocene sequence. The succession on the east coast is not the same as on the west, the Paparoa and Brunner Beds being absent.

At the close of Eocene times Benson⁶¹ maintains that the mountains which had been formed during the early Cretaceous movements had been reduced nearly to a peneplain, and that a marine transgression spread over the greater part of the South Island and also over much of the North Island. But the central part of Otago seems to have remained a land-area, and on it accumulated the fluvialite and lacustrine deposits of Miocene and perhaps Pliocene times which are often auriferous.

Oligocene-Miocene.—The *Oamaruan System* as now restricted covers this Tertiary period in Europe, but while Allan⁸⁵ includes only the stages above the Bortonian to the Awamoan in it, Finlay and Marwick⁸⁹ would include Allan's Taranakian System. The faunas of the different stages and localities show considerable peculiarities, as for instance at Chatton, Southland¹¹⁰.

Broum Coal-Measures occur on the east side of the South Island at the base of the Oamaruan marine beds^{22 29}, but the marine beds are the most important deposits, and are developed especially on the east coast of the South Island. They are also developed over a considerable area on the west of the North Island, and outliers of them occur on the shores of the Hauraki Gulf and elsewhere, as for instance at Whangarei^{20 123}, where the frequent occurrence of the foraminiferal genus *Amphistegina* is held to point to a Miocene age for certain of the limestones⁹⁴.

Chapman⁸⁶ considers that the relationships of the abundant Oamaru fauna are with the Miocene (Janjukian) of Victoria in Australia, and the whole Oamaruan Series was referred by Park⁵¹ to the Miocene. Marshall²⁰ went so far as to maintain that all the younger limestones of New Zealand, whether polyzoal, foraminiferal, or of the nature of a globigerina ooze, were of Miocene age. It is highly probable, however, that part of the Oamaruan Series belongs to the Oligocene.

The Oamaruan System is best developed in Otago¹²⁷ and Canterbury¹²⁹, where the marine beds are richly fossiliferous. The whole formation is here of

littoral and shallow-water origin, and indicates progressive submergence of the shore-line. One of the best studied sequences is at the type-locality Oamaru^{22 51}, where the basal Brown-coal-seams, sands, and conglomerates are of fluvial origin, and are followed by marine sedimentary and volcanic rocks, including the Waiareka tuffs, diatomaceous earth and Enfield-Windsor greensands. Above them comes the marine 'Oamaru Limestone,' which is used for building; it gradually decreases in thickness and ultimately dies out westwards. This has been termed by Thomson^{22 83} the *Ototaran Stage*, and is regarded as equivalent to the Middle Oligocene. It underlies the Hutchinsonian and contains characteristic brachiopods. Above it are more marine greensands, blue clays, etc., forming the Waitakian, Hutchinsonian, and Awamoan Stages. The beds are rich in fossils, including lamellibranchs, gastropods, and brachiopods^{17 46}. Volcanic activity⁴⁶ was prevalent but intermittent during this period; and tuffs, breccias, and lava-flows (including pillow-lavas) are frequently interbedded in the sedimentary series, and in character and relations point to submarine eruptions. Basalts and dolerites occur around Oamaru, and many basaltic cones which are found between Oamaru and Dunedin are referred to this period. To the east and south of Lake Te Anau there is a long wide strip of fossiliferous Oamaruan beds down to Te Wae Wae Bay¹⁴⁷.

In the North Island in the New Plymouth area³² the beds which correspond to the Oligo-Miocene of the South Island are petroliferous, and consist of fossiliferous claystones, sandstones, and conglomerates containing the usual marine fauna. An unconformity separates them from the overlying Mio-Pliocene pyroclastic and sedimentary beds which are associated with some lignites and lava-flows; these rocks are unconformably succeeded by Pleistocene deposits. In the Egmont¹⁰⁹ and Tongaporutu-Ohura¹⁰⁶ subdivisions of the Taranaki Division the Miocene beds are classified somewhat differently from those in the South Island, and have received local names. The Lower Miocene is represented by the Makakatino, Mokau¹⁴⁸, and Mahoinui beds, and succeeded by the Urenui and Tongaporutu beds of Upper Miocene age, all of which are highly fossiliferous and composed of marine arenaceous and argillaceous deposits with conglomerates. In the Taranaki coalfield there are coal-seams interstratified with the marine beds. The oldest coal-seams are probably of Middle Oligocene (*Ototaran*)⁸⁵ age, but the higher, or *Mokau Series*, has a marine fauna indicating a Miocene age corresponding to the Awamoan and Hutchinsonian, and the principal coal-seams are in this series¹⁴⁸. Marwick⁸³ has correlated these series with those in the Gisborne district on the east coast. The Waitotara^{95 96 111} Stage follows and is of Lower Pliocene age. In the Waiapu subdivision¹⁴⁹ in the Rauhumara Division, North Island, an abundant foraminiferal fauna¹⁵⁰ has been described from Oligocene or Lower Miocene beds. These beds were divided by Ongley and Macpherson¹⁴⁹ into several series, but Marwick⁸³, on a more detailed study of the mollusca of the Gisborne district, has divided them into three stages, to which he gives distinctive names, and has correlated them with the Hutchinsonian (Upper Oligocene), Awamoan (Lower Miocene), and Taranakian (Upper Miocene). A lower series is correlated with the *Ototaran Stage* (Middle Oligocene), and it rests unconformably on the Cretaceous. In the intermontane basins of the South Island there are large and thick deposits of gravels and conglomerates, such as the Kurow Series¹⁶⁸ in the Waitaki Valley, and the Benmore and Glentanner beds in the Mackenzie basin¹⁰⁴, which rise to heights of 2300-4000 ft. above sea-level, and from 700-2500 ft. above the adjoining plain or valley, and are in places strongly tilted or folded. They may be of Mio-Pliocene age and antedate the latest diastrophic movements. The auriferous quartz conglomerates of the Waimumu Gold-field¹⁸¹ in South-

land are older than the marine Ototaran (Oligocene) sandstone and clay which overlie them. The brown coals of Auckland are referred to the Oamaru System. The petroliferous beds of Poverty Bay have been referred⁸⁸ to the Upper Miocene, and the marine fauna which they contain is said to resemble that of the Patagonian Molasse. In this district the beds have suffered considerable but somewhat irregular folding.

Of later date than the Oamaru Series above described are the volcanic rocks of the Otago Peninsula¹⁴¹, some of those of the Banks Peninsula^{102 132 170 171}, and some of the Hauraki Peninsula^{31 41} (see below). These belong to the great period of vulcanicity in New Zealand, which began in Middle or Lower Miocene times, and has lasted in the North Island to the present day. In the Otago Peninsula¹⁴¹ there is a first period of activity represented by phonolites, dolerites, trachydolerites, etc., with tuffs and agglomerates resting mainly on eroded sandstone of Oamaru age. Overlying these lavas and filling hollows on their denuded surface are fresh-water shales and sandstones, with seams of lignite. Dykes of nepheline-syenite, augite-dolerite, and tinguaitite pierce the lavas. Volcanic rocks of the same general type, but belonging to the second period, overlie them.

In Banks Peninsula^{48 102 132 170 171} the flows of rhyolites and beds of tuff of Cretaceous age are succeeded by a period of denudation and the deposition of sandstones, and then follow further volcanic outbursts represented by andesites and basalts in great flows of Tertiary age. Lyttelton and Akaroa¹⁰¹ Harbours on this peninsula occupy old volcanic craters of the caldera type, surrounded by crater-rings breached by the sea at one place. The second volcanic phase of this peninsula was marked by the pouring out of these basic lavas which, together with ash-beds, built up the Lyttelton and Akaroa cones. An immense number of dykes, chiefly trachytic and alkaline, radiate from the former. A third and fourth phase of activity are also recognised, with outflows of basaltic lava⁹⁰.

In the Hauraki Peninsula^{31 41} there is an immense mass of andesitic lavas, tuffs, and agglomerates, of which the dominant type is an hypersthene-augite-andesite with which many of the auriferous veins are associated, as at Waihi. These volcanic rocks rest in places on denuded older Tertiary and Maitai beds, and belong to three periods of eruption³¹. The lavas and tuffs of the third period are entirely of a rhyolitic or dacitic character, and overlie the andesites and the few dacites of the earlier periods. The age of the first series is believed to range from the Upper Eocene to the Lower Miocene, while the second and third series are tentatively referred to the Miocene and Pliocene respectively. Widespread hydrothermal action belonging to more than one period has altered the andesites into propylites, and led to the formation of the gold and silver veins. In each period in the Hauraki Peninsula intrusive rocks and dykes were injected, but the post-rhyolitic dykes are of special interest petrologically, because they are similar in composition to the initial andesites⁵³. The Hauraki Province otherwise shows in its volcanic eruptions an increasing acidity in three well-marked steps. The propylitisation and mineralisation of the rocks appear to have taken place in some areas at one period only, but in others at three (*e.g.* in the Thames subdivision).

In the Coromandel district⁴³ three periods of volcanic activity in Tertiary times are likewise recognised, the rocks of the first two being almost wholly semi-basic or intermediate, and those of the third acidic, and probably of Pliocene age. The earliest lavas of the first period are acidic, and consist of rhyolites, but the main mass of the volcanic rocks of this period consists of andesites or dacites, which have suffered widespread propylitisation. They rest on folded and denuded Jurassic or pre-Jurassic beds, and in places on fossiliferous Tertiary (? Eocene) beds. In the second period (Miocene) andesites and

dacites were poured out around and over the earlier series, and pyroclastic rocks are conspicuous, tuffs and breccias being greatly developed. The third period is characterised by pyroclastic acidic rocks through which flows of spherulitic rhyolites have taken place. In the Rotorua-Taupo subdivision^{69 154} the volcanic rocks range in age from the Miocene to Recent. The oldest lavas are Miocene, and consist of hypersthene-andesites; the Pliocene lavas are rhyolites of more than one type and include also andesites and basalts, together with breccias and ignimbrites (see below). This zone of volcanic activity is situated at the apex of an acute angle formed by the divergence of the two main structural axes of the North Island and is in the line of the Tonga-Kermadec Islands line of vulcanicity¹⁵⁹.

The peculiar rocks which have been called 'ignimbrites' are tuffaceous deposits of minute fragments of acid volcanic rocks, probably deposited as fine glowing volcanic dust which has become fused into sheets when red-hot, resembling lava-flows. Such are found in the Taupo-Rotorua district¹⁵⁴, and are of Pliocene age.

In the north-western portion of Manukau County, Auckland, the Waitemata Series of supposed Miocene age consists partly of volcanic tuffaceous sandstones and grits containing abundant foraminifera¹⁵⁵.

Pliocene.—A great succession of marine and fluvio-marine beds, resting unconformably² on the Oamaru beds, and comprising clays, sandstones, sands, conglomerates, and a few limestones, is mostly referred to the Pliocene, and is termed the *Wanganuian*. But Allan⁸⁵ considers certain lower stages should be separated as the Taranakian System, and that they bridge over the gap between the Oamaruan (Miocene) and the Wanganuian (Pliocene). In the North Island these beds, as at Wanganui¹¹³ and in the Gisborne district⁸³, yield an abundant fauna, of which about 70 per cent, to 90 per cent, belong to living species, and are very different from those of the Oamaru System. No marine Miocene beds are known in the North Island north of the East Cape district, nor in the South Island south of Middle Canterbury. But thick unfossiliferous gravels (Moutere gravels) of supposed Pliocene age exist in the South Island^{23 38}, and some old lake-basins in Otago^{30 156}, containing gravels, clays, and some lignites with plant-remains, are probably of this age. Many of the volcanic rocks in the North Island also belong to this period.

Of the various groups of strata in this system only the lowest is found in the South Island, and it is represented by the *Awatere Series*, which is included in the Taranakian by Finlay⁸⁹, and comprises the Awatere Beds of Marlborough¹⁰⁷ and the Greta and Motanau Beds of North Canterbury. The characteristic fossils of this lowest series are *Strutimorhi sulcata*, (*Cardium spatiosum*), and *Scaphella corrugata*, which are restricted to this horizon. The Awatere Series is specially developed in the North Island in Wellington, Hawke's Bay, and Auckland, while the succeeding Waitotara and Petane Series are also specially developed in the Wellington and Hawke's Bay districts. The Waitotara Beds^{95 95A 131} consist chiefly of shelly coralline crag and calcareous sands, which are well developed in the Huntly-Kawhia district¹⁸¹. They are referred by Marwick approximately to the Lower Pliocene, but Park² had put them in the Upper Miocene.

Of the fossils the genus *Struthiolaria* is specially characteristic of the lower or Awatere Beds, while large species of *Pecten* and an oyster (*Ostrea ingens*) are typical of the Waitotara beds⁷. In the Mount Egmont district⁸⁴ the Waitotaran beds reach a thickness of 2000 ft. The Nukumarooan⁹⁶ and Castlecliffian Series include the highest stages of the Pliocene and are developed at Hawke's Bay and Wanganui^{96 113} respectively⁸⁵. The Castlecliffian or Petane beds, which consist of sandy shell beds, blue marine muds full of fossils, etc., contain

about 95 per cent, of Recent species, and are specially fossiliferous at Wanganui¹¹³.

It appears from the mode of distribution of the marine beds that the South Island began to rise before the North Island, and this elevation, in addition to causing the non-deposition of the later Pliocene beds in much of the South Island, may have helped to induce the Pleistocene glaciation in that Island (see below), of which there is only doubtful evidence in the North Island.⁸ These Pliocene marine beds in the latter occur up to a height of 4000 ft. in the Ruahine Range, pointing to considerable late movements of elevation. A clear connection between changes in the marine molluscan faunas and climatic variations in Pliocene times has been claimed by Fleming¹⁸⁴.

The volcanic activity of this Pliocene period was concentrated in the North Island¹⁰⁵, but some of the eruptions in the South Island (*e.g.* in Otago)^{140 141} may have occurred at as late a date. In the North Island there was a great outpouring^{24 41 69 154} of rhyolitic lavas, tufts, and pumiceous agglomerates; many of the lavas are banded, and most are spherulitic, and in many places have been highly silicified by secondary processes. In the Hauraki district these volcanic rocks rest on the worn surface of the earlier andesites and dacites, and for the most are horizontal. Some basic lavas (dolerites and basanite) found in Auckland and in the Waikato Valley are probably also of Pliocene age. The eruptions of hornblende-andesite lavas which built up Mount Egmont⁸⁴, and the hypersthene-andesites which were poured out from Ruapehu⁶⁹ and its neighbours, probably began during Pliocene times, but in the former case are chiefly Pleistocene. The volcanic eruptions in the North Island^{55 69} continued into Pleistocene and Recent times, but the chronological separation of them is difficult. In the great volcanic plateau in the centre of the island, the eruptions of later andesites and related rocks break through the rhyolites, and have been prolonged to the present day (see below). In the Tarawera district¹²² the solfataric stage of vulcanicity is now dominant, but the earlier eruptions took place in Plio-Pleistocene times.

Late Tertiary Earth-Movements.—It is a matter of dispute as to how much the present relief of the country is due to the orogenic movements which followed the Notocene period of deposition. Some geologists^{3 4} attribute the formation of such ranges as the Kaikouras¹⁵⁷ to these movements (Kaikouran deformation), and consider that the young faults have played an important part in the structure of both islands. The reversed faults in the Kaikouras dip steeply to the west¹⁵⁷, whereas most of the reversed faults elsewhere dip to the east. The block-faulting⁶¹ and the development of reversed faults and of structural basins which are conspicuous features in the South Island are believed to have taken place during late Pliocene times^{23 134}, while horst-like masses in the North Island (as in the Hauraki district⁵³), from which the covering strata have been removed, suggest the extension of these movements northwards. Other geologists do not admit that these disturbances were so intense or effective, and believe that only regional uplift and subsidence occurred in late Tertiary times. Park has shown that the main group of table-topped ranges in central and northern Otago, which rise to heights of 5000-5500 ft. above sea-level, are true block-mountains (horsts) separated by flat-bottomed basins from 500 to 1000 ft. above sea-level filled with lacustrine and fluvial deposits, of which the former deposits 'are deeply involved in the great fractures that run along the foot of the ranges,' while the fluvial deposits, 'of glacial or post-glacial age, rest on the upturned edges of the lacustrine series.'

In the North Island the late origin of some of the major faults, notably that traversing the Thames Gold-field in a north-west to south-east direction, is

generally admitted⁵⁸, and Park attributes the movements to the newer Pliocene, or even early Pleistocene. In the North Island in Manukau¹⁵⁵ and Franklin¹⁶⁶ Counties, Auckland, there is a series of transverse faults at right-angles to the major faults breaking up the country into rectangular blocks. In the North Island in the Rotorua-Taupo subdivision there is a great rift-valley, or, as Grange⁶⁹ terms it, a 'down-faulted, down-warped graben,' extending in a north-north-east direction and situated in a former volcanic plateau which has been much faulted. The floor of the graben has been made very irregular owing to other later faults which have broken it up into separate blocks, and these have themselves been tilted or warped and more or less covered by lava-flows. Lake Taupo¹⁵⁴ occupies the southern end of the graben and has a remarkably flat floor with a depth of 350-400 ft.

Late Pliocene and Pleistocene earth-movements are believed by King¹³⁴ to have accounted for the separation of the North and South Islands; the South Island in a first stage moved west. A second stage moved the South Island with the Marlborough Sounds block farther westward, making the severance complete. In the early stages the New Caledonia ridge from the North Auckland Peninsula was complete; the East Cape-Kermadec-Tonga ridge was later formed and buckled the earlier ridge accompanied by overthrusts and overfolds to the east. The earthquake lines follow mostly the south-west to north-east trend of the Pliocene orogeny in both islands.

PLEISTOCENE AND RECENT (=NOTOPLAISTOCENE of Thomson)⁴⁹

The boundary between the Pliocene and Pleistocene beds in New Zealand is occasionally hard to determine. But Marwick¹⁶⁴ has enumerated several criteria, amongst which one of the chief indications is that the Pliocene deposits have usually been disturbed and folded by the 'Kaikoura deformation' (of Cotton), whereas the Pleistocene has not suffered from these earth-movements. The percentage of living species of mollusca, etc., where the deposits are fossiliferous, is another but unsatisfactory criterion.

In the North Island there are gravels resting unconformably on Pliocene beds along the western coast, which are referred to the Pleistocene (Notopliocene of Thomson⁴⁹). In addition to these there are various fluvial deposits, often of considerable coarseness, but some geologists would attribute certain of these accumulations of coarser material to glacial agencies. Many of the lower-level deposits of gravel¹⁰⁴, such as are spread over the floors of the intermontane basins like the Mackenzie¹⁰⁴ in the South Island, are due to the outwash from rivers issuing from the ice-fronts of the older or younger glaciation. Others may be of interglacial origin. The older gravels of North Canterbury¹⁶² south and south-east of Mount Grey lie in basins of the Kowa and Grey rivers and rest on Upper Pliocene beds. They are earlier than the gravels of the Canterbury Plains, and in places have suffered folding. The gravels of the Canterbury plains¹⁶² afford a fine example of Piedmont aggradation which went on during the wearing down of the mountain areas. This sheet of gravel extends over an area 130 miles long and 30 miles wide and is composed of the confluent fans of the rivers draining the eastern slopes of the mountains and partly built out over a sea-floor which subsided several hundred feet during their formation.

It is in the South Island³⁶ that undoubted glacial deposits¹⁴³ are most plainly and widely developed, particularly in the Lake Wakatipu region³⁶ and in south-west Fiordland⁷⁰. Glacial moraines and drifts are here abundant, and have been classified into an older and a later series, marking two phases of glaciation, an ice-sheet phase and a valley-glacier phase, the latter having two or more inter-glacial stages. Of the older series in the South Island the

Taieri and Clutha moraines in Otago are best known, and in the North Island there is the supposed andesitic moraine in the Hautapu Valley in Wellington¹¹.

The later series of glacial deposits is represented by the boulder-clays and moraines of the Wakatipu area, where also *roches moutonnees* and erratics and other evidences of ice-action are found; other moraines of this later series are seen in Marlborough (e.g. near Cape Campbell). On both sides of the Southern Alps the former greater extension of the glaciers and the much greater thickness of ice are evident. Trechmann⁸ has expressed the view that there is no evidence of the existence of a true ice-sheet, but only of an Alpine type of glaciation.

The sounds and inlets of Westland are regarded either (1) as drowned glacial valleys^{102 105}, (2) as pre-glacial tectonic valleys^{52 152}, due originally to the intersection of two or more sets of parallel faults which have formed trough-like depressions of a true fiord nature, and have been more or less occupied and modified by ice-action; or (3) as due to the excavation by ice of previous valleys of erosion during the glacial period⁴⁰. All the sounds occupy basins, but the nature and origin of the thresholds are matters of dispute. According to some geologists⁷⁰ the Fiordland peneplain, which is now thoroughly dissected, was uplifted in late Cretaceous or pre-Tertiary times, but according to others⁷⁰ the uplift did not take place till after mid-Tertiary times and was accompanied by extensive faulting and some folding of the rocks, followed by the development of the great peneplain. In the Preservation region a slight undulation (north-east to south-west) resulted in the formation of consequent drainage systems, and a lower peneplain. The fiords of the western coast of the South Island are regarded by some geologists as drowned valleys, resulting from the depression of the coast¹⁰⁵ after a long period of erosion rather than to faulting of the margin of the land.

The lakes are of varied origin²⁵, but some have been formed in connection with the glaciation; others, such as Te Anau, seem to be due to trough-faulting, others again to warping of the surface or formation of dams by glacial deposits. Pleistocene or Recent earth-movements have in many cases formed the basins¹⁵⁶. The large lakes¹⁵⁴ in the volcanic region of the North Island are due to subsidence, faulting, and warping of the surface, but there are also some true crater-lakes such as on Mount Ruapehu and Tikitapu⁶⁹. The great crater of Rotomahana is now also filled with water. In the case of Lake Wakatipu seven or more old beaches, rising to a height of 150 ft. above its present level, can be traced round its shores. In addition to the glacial deposits there are the silts, clays, sand-dunes, and peat-bogs, partly of Pleistocene and partly of Recent age, which contain the remains of the Moas (*Dinomis*) and other extinct birds, some of which lived on into the human period.

Raised beaches are found in the South Island up to 1000 ft. (Foveaux Strait). But coastal terraces^{105 135 167 189} and Raised beaches occur all round both islands and belong to two sets—one set ranging to 120 ft., and the other up to 200-300 ft.; there are also beaches at 400-600 ft. These all indicate movements of elevation in Pleistocene and Recent times^{184 189}. Evidence of depression along the coast is afforded by the Westland fiords^{70 152}, and by some inlets and bays on the North Island, if we regard them as drowned glacial or pre-glacial valleys rather than faulted troughs.

Throughout the Pleistocene period volcanic activity continued in the North Island^{55 69 84}, as above mentioned, but none has been found in the South Island definitely referable to this date. Andesitic lavas were poured out from Egmont. The volcanic rocks of this mountain⁸⁴ include not only these andesitic lavas, but also breccias, conglomerates, and tuffs, some of which have been deposited under water. Hutton¹⁸⁰ has described many types of igneous rocks of Plio-Pleistocene age in this area of New Plymouth³². The

whole series has been termed the *Pouakai Series*³² and follows on the Pliocene 'Waitotara Stage' of the Wanganui System. On the interior volcanic plateau the eruptions have lasted until the present day. The volcanic craters near Auckland and the Bay of Islands likewise show by their perfect shape and the unweathered condition of the lava-flows that they are of no great age. Parallel to this western marginal zone is the main series of active or dormant volcanoes, Ruapehu and Tongariro, mostly having high cones of accumulation which are closely related to each other and are arranged in an almost direct line through the centre of the North Island, running from Ruapehu in a north-easterly direction to the Bay of Plenty parallel to the major axis, and also to a zone of Assuring (the Whakatane fault). Associated with them are hot-springs¹⁰⁸, geysers, solfataras, etc. The series of vents is continued by White Island in the Bay of Plenty, which was active in 1914, and Speight considers that the Kermadec and Tonga volcanoes are on the same line¹⁵⁹ which reaches still farther to Samoa and even to Hawaii¹². Mayor Island¹¹⁴ in the Bay of Plenty is the upper part of a volcano and at its highest point is about 1200 ft. above sea-level. The crater has a diameter of 1½ miles. The island is composed entirely of alkaline rhyolites (comendites) and obsidian. The volcanic phenomena of the present day in the North Island are small compared with those of the past, and are mostly of a solfataric type. As above stated, the Rotorua-Taupo area⁶⁹ has lavas of various ages spread over it. The chief volcanic rocks in that area are rhyolitic^{69 154}, except in the south-west, where they are andesitic, as in the Tongariro-Ruapehu subdivision. The numerous volcanic mountains in this region are rarely conical or with a crater; most are composed of rhyolite and have a dome-like shape. A peculiar tuff formed of the fine dust and fragments of acid rocks in the Taupo-Rotorua district has been termed ignimbrite by Marshall¹⁸⁷. The Haparangi Series of rhyolites is of Pleistocene age and occupies large areas near Lakes Tarawera¹³² and Taupo⁶⁹; they were erupted in a viscous state and form craterless flat-topped domes. Recent explosive eruptions have formed craters, such as the great Rotomahana crater from which basalt was first ejected and then mud composed of fine volcanic fragmental material or sand with superheated water. The Taupo plateau⁵⁵ is now the chief scene of activity. In the case of the Tarawera¹²² eruption in 1886, a fissure was opened nine miles long, with a width averaging ten chains, and it seems that the andesitic lava welled up in it before the explosion took place which spread the volcanic materials over an area of nearly 6000 sq. miles, and to a depth in places of 50 ft. This eruption is supposed to have been caused by the access of the water of Lake Rotomahana to the deep-seated hot magma when the fissure opened, causing the huge explosion and the formation of numerous craters along it⁶⁹, with the discharge of masses of ash from Tarawera¹²² and of wet mud from Rotomahana which flowed as a lava-stream. The siliceous incrustations, known as the White and Pink Terraces, which had been deposited by thermal springs near Lake Rotomahana, were completely destroyed at that time. But many hot springs^{69 108}, geysers, boiling mud-pots, and solfataras in the Taupo-Rotorua district are still active, and point to dormant volcanic energy.

ECONOMIC GEOLOGY¹⁰⁸

Coal^{2 10 27 29 108 144.}—There are no Palaeozoic coals in New Zealand. Two main Tertiary coal-bearing formations occur in the South Island. The older or Bituminous (Upper Eocene Waimangaroa Series) Lower Coal Measures occur chiefly in western Nelson, where they are worked in the Greymouth^{2 23 146} and

Westport²⁹ districts, and at other points on the west coast. The Buller-Mokihinui Coalfield²⁰ is one of the most important. The newer (Miocene) or Brown Coal Measures are worked also in various parts of Nelson and in Otago¹⁴⁷ and Canterbury, but are of less value and of many grades. A third less important set of coal-bearing beds, older than either of the above mentioned, being of Cretaceous age, occurs at Shag Point, Otago, and in the Malvern Hills, and in the North Island coal of this age is also worked in North Auckland.

Lignites and brown coal of Pliocene age also occur in central Otago in old lake basins² and Pleistocene lignites² are extensively distributed in Southland.

In the North Island the coal beds mainly belong to the Miocene or Upper measures, and are worked in the Waikato coalfield². But in the Huntly-Kawhia subdivision the Tertiary coals belong to the lowest Tertiary in the series, and are regarded¹³¹ as of Oligocene or possibly Upper Eocene age. The Mokau¹⁴⁸-Upper Wanganui field is the largest in New Zealand, measuring 35 by 40 sq. miles, and may be considered the southern extension of the Waikato field. The coal from these fields comprises the so-called pitch-coals.

The New Zealand coals vary much in quality, and range from anthracite to lignite ; only about 37 per cent, of the proved total resources consist of bituminous coal, practically all the rest being brown coal.

The seams are lenticular and mostly impersistent, frequently thinning out.

Petroleum¹³⁷ has been obtained by boring in Tertiary and Cretaceous rocks in many areas¹³⁷, though not in commercial quantities. It occurs in Miocene (Oamaru) strata near New Plymouth, Taranaki^{32 148} ; near Poverty Bay^{33 87}, in the North Island; and near Grey mouth and at Lake Brunner in Westland²³. The Taranaki region is said to possess oil seams at various depths to 3000 ft., and is the most promising. Gas wells also occur in this district. In the Greymouth district the oil-bearing rocks also seem to be of Miocene age²³, and the geological conditions appear to be favourable for its occurrence. In the Kotuku oilfield¹⁸⁵, south-east of Greymouth on the west coast of the South Island, oil-seepages led to wells being sunk, and bores to a depth of 1300 ft. have been drilled. Some oil has been struck in these bores, but by far the greater amount of oil occurs in the surface gravels and in the upper coarse late-Tertiary rocks. It was formerly held that the oil had a deep-seated origin and came from the mudstones, shales, and coals of the Brunner and Paparoa Series of Eocene and Upper Cretaceous age. But it is now probable that its source is the Blue Bottom Formation of Pliocene and Miocene age, which consists of gravels,

shales with lignite, blue sandstones, clays, and limestone, with a total thickness of 1200 ft., below which are Oligocene limestone, calcareous sandstone, and claystone, and then Eocene sandstones, shales, and mudstones about 4000 ft. in thickness. It is believed that a gentle anticlinal structure is present.

Oil-shales of Tertiary age are found in the Nevis River area of Otago¹⁷⁴ faulted into the schists, and associated with lignites, quartz grits, and sands and conglomerates. The beds are mostly folded and are the highest Tertiary beds of the area. In other parts of the South Island oil-shales have also been discovered.

Phosphates^{108 126 128}.—Marine phosphatic horizons¹²⁶ occur in the Tertiaries in many parts of New Zealand, but especially in south Canterbury and north Otago. In south Otago the phosphates occur in pockets in the limestone at Clarendon. The Weka Pass Stone and Amuri limestone in north Canterbury and Marlborough are probably pre-Otataran (pre-Miocene), but the other occurrences are of Otataran or Hutchinsonian age. The phosphate occurs as phosphatised pebbles in conglomerates, or as phosphatic cement or nodules. In the Waihao limestone of the Otataran Stage of the Oamaruan System there is also a nodular phosphatic band¹²⁷.

Building and Ornamental Stones.—In the South Island the Ruapuke diorite of Bluff and some basalts are used for building purposes, but the chief building stone is the Miocene Oamaru stone or Otataran Limestone of Otago. The nephrite or true jade of the Pounamu Formation⁴² is well known, and occurs in the talc or serpentine intrusions penetrating the 'Greenland Series' in the South Island.

Gold.—(a) *South Island.* In Otago²⁷ quartz-veins occur as fissure veins, bedded veins, or crush or shear veins in the chlorite- and mica-schists of supposed Maitai age. All are epigenetic, and the lodes occasionally carry scheelite as well as gold. The alluvial gold of this district, which is found in various types of deposit, is probably derived from these rocks. Some of the drifts are of Pliocene age. The quartz-conglomerates in Otago and Southland^{147 181} which are auriferous are river-gravels. Some are older than the Middle Oligocene at Waimumu.

In Reefton¹⁴⁶ the gold-bearing quartz-veins occur in a series of sharply-folded mudstones and sandstones referred to the Maitai System, and are said to run parallel to the bedding as sheet-like segregations of quartz or as bedded lenses.

The Westland alluvial deposits are comparable to those in Otago, and have been referred to various dates ranging from Mio-Pliocene to Recent²³, but those which are worked are of Pleistocene or Recent age.

(b) *North Island*.—In the Hauraki Peninsula³¹¹⁴⁶ the Miocene andesitic lavas and ashes are succeeded by rhyolitic lavas of Pliocene age, as above described, and after both volcanic outbursts there was great hydrothermal activity which caused the formation of the metalliferous veins and produced the alteration of the andesites. The richest gold-bearing veins occur in the andesitic lavas and were formed along lines of fracture ; they consist mainly of large well-defined bodies of crystalline quartz, or of chalcedonic sinter-like quartz, but these types occur at slightly different horizons.

Silver occurs as argentite and in other ores in the gold veins of the Hauraki Peninsula and elsewhere in Auckland.

Iron.—The Parapara⁴⁴ ironstone deposits in Nelson are mainly of limonite and are of great extent. The ore occurs along the junction of a quartz-schist and a cherty limestone, and occupies the crest of a complex anticlinal fold. The iron-ore is apparently in all cases the result of the oxidation of ferrous carbonate, and the deposit is regarded as largely due to metasomatic replacement. The enclosing rocks, which may be of Palaeozoic age, are unconformably overlain by Tertiary clays, sandstones, and limestones. In the North Island the Taranaki iron-sands, which contain 60 per cent, of iron (but are titaniferous), are of the nature of river- and beach-deposits derived from basic igneous rocks ; the iron occurs in separate grains of magnetite and ilmenite, and forms seams or lenses of pure black sand interstratified with beds of felspathic quartz-sand.

Chromite.—Chromite is a common constituent in the serpentines, peridotites, and ultrabasic rocks of the South Island. The peridotites of Nelson, the intrusion of which was later than the folding of the Upper Jurassic, have been worked for the ore, which is often found in large masses³⁴.

Copper^{27 34}.—The best-known deposits are found in a mineralised zone stretching southwards from D'Urville Island to the Aniseed River, near Nelson, and the ore-deposits lie along the planes of stratification of the argillites near their contact with sills or bosses of dunite³⁴.

Tungsten²⁷.—Scheelite occurs in quartz-veins traversing mica-schists in parts of Otago and Marlborough, and is always associated with gold.

Platinum.—This metal occurs in alluvial gold-drifts in Southland and in sands at Orepuke and near Takaka in Nelson. In Westland there are found platiniferous quartz-veins close to altered magnesian eruptives and parallel to the stratification of the enclosing phyllites ; the platinum is here associated with silver.

Mercury has been found and worked in the Whangarei Bay of Islands subdivision¹²³. It occurs as an ore body in a rubbly mass of siliceous sinter resting on altered greywackes and overlain by a basaltic lava-flow or sheet¹⁸². It has been introduced by thermal solutions.

Nickel is found in the gravels and sands of certain rivers in Otago, and is derived from peridotite and serpentine.

Nephrite^{73 74}.—The so-called jade from which the Maoris made their axes and 'tikis' was obtained from the 'greenstones' and serpentines of various places in the South Island^{73 142}.

Graphite.—This mineral is widely distributed in the older metamorphic rocks^{70 108 158}.

Talc.—In the intrusive basic and ultrabasic rocks altered by hydrothermal action, and invading the Maitai schists and quartzites at the north-west end of the South Island^{172 173}, talc occurs in veins or lenses, especially along the contact zones.

OUTLYING ISLANDS OF NEW ZEALAND¹²⁹

The **Chatham Islands**^{276 151} lie between the parallels of 43° 30' and 44° 15', S. latitude, and in longitude 177° W. The largest island, which has an area of about 350 sq. miles, possesses schists of supposed Maitai age, striking south-west-north-east. Limestone of supposed Palaeozoic or possibly Tertiary age also occurs. There are also fossiliferous calcareous tuffs and limestones which contain *Woldheima*^{93 110} *Pecten*^{92 111}, bryozoa, and other organisms, and seem to belong to the Oligo-Miocene (Oamaru System)⁹²; brown coal is found in Pitt Island at the base of the series. Volcanic rocks cover the greater part of Chatham and Pitt Islands, and include basalts, palagonite tuffs, limburgite, and trachytic tuffs.

The Bounty Islands (lat. 47° 43' S., long. 179° E.) consist entirely of a biotite-granite⁹.

The Snares Islands (lat. 45° S.) are composed of muscovite-granite, somewhat gneissose⁹.

In the **Auckland Islands**⁹, in lat. 50° 40' S., about 190 miles south of Stewart Island, the oldest rocks consist of masses of granite and gabbro, which are overlaid by a tuff and flows of alkaline trachyte, and are penetrated by dykes of the same rock as well as of diabase and porphyrite. These are succeeded by a conglomerate containing rounded pebbles of these granites, gabbros, and trachytes and also pebbles of gneisses, schists, and granites of different types. This conglomerate proves the proximity of a continental area, and is probably an old river-deposit. A series of porphyrites and

diabases follows next in order, and consists of flows which in one case have a thin bed of anthracite between them, probably representing a layer of peat. Dykes of dolerite, diabase, and porphyrite occur in association with these lava-flows. A younger series of basic lavas forms the greater part of the islands, surrounding Carnley Harbour, which is undoubtedly an explosion crater or caldera subsequently modified by marine and sub-aerial erosion. Other volcanic foci probably existed to the north. The lava-flows constitute a remarkably regular horizontal series of beds with intervening layers of tuff, and number in one place forty-two in succession. They show columnar structure and include basalts, dolerites, and olivine-augite-andesites. From their freshness and the well-preserved caldera walls, it is inferred the eruptions are of Middle or late Tertiary age. As in the case of the older lavas there are dykes of diabase and basic porphyrites and dolerites which may be contemporaneous with them.

The presence of extensive moraines and other glacial features on the surface indicate a former glaciation probably contemporaneous with that of Pleistocene times in New Zealand.

Campbell Island²⁹, situated in lat. 52° 30' S., and long. 159° 8' E., appears to possess a basement of mica-schist; then follows an olivine-gabbro, which is probably intrusive and forms Mount Menhir; on it rests unconformably a thick series of marine sediments consisting of sandstones 10 ft. thick, with quartz-pebbles derived from the schist, and shales (50 ft.), capped by limestones with flints (500 ft. thick). These beds dip eastward at small angles and are traversed by faults. The mass of the limestone, which is mostly crystalline, is formed by foraminifera (*Globigerina*, etc.), and other fossils, some of which indicate an Upper Cretaceous age, but others point to a Tertiary (Miocene) age, for they occur in the Oamaru beds in New Zealand. A volcanic tuff which rests with an apparent unconformity on the limestone is about 500 ft. thick, and contains further marine fossils identical with those in the Upper Miocene of New Zealand. Overlying this are lavas, of which the lower ones are trachytes, but the upper ones are basalts or dolerites, together with others of intermediate composition. A phonolite is also known from the island. Dykes of trachyte and basalt intrude all the rocks (except the gabbro), and are especially numerous in the limestone. From the presence of this varied series of rocks it is clear that Campbell Island once formed part of a much larger mass of land, but its precise connection with New Zealand is undetermined.

Macquarie Island (lat. 54° 30' S.), so far as it is known, is composed of dolerites and basalts.

The Antipodes Islands (49° 41' S. lat.), which are composed of regular flows of basalt and beds of scoria, seem to be entirely of volcanic origin.

General Remarks.—It is probable⁹ that the Auckland Islands, the Snares, the Bounty Islands, and possibly Stewart Island and south-west Otago are unsubmerged remnants of one great continental mass of granite which constitutes the foundation of the later rocks.

According to Park² the New Zealand continent probably extended in Pleistocene times from New Caledonia in the north to Macquarie Island in the south, with the Chatham Islands situated near its easternmost point at its broadest portion, and the Antipodes and Campbell Islands along its south-eastern margin. The greatest extension of the continent thus lay to the south-east of the present South Island of New Zealand.

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- B.I. Bay of Islands.
- B.P. Bay of Plenty.
- G.B.I. Great Barrier Is.
- H.B. Hawke's Bay.
- H.G. Hauraki Gulf.
- K.H. Kawhia Harbour.
- Kp.H. Kaipara Harbour.
- M.E. Mount Egmont.
- M.H. Manukau Harbour.
- M.R. Mokau R.
- P.B. Poverty Bay.
- Ro. Rotorua.
- T. Taupo.
- W. Wellington.
- Wa. Waikato.
- W.H. Whangarei Har-
bour.

SOUTH ISLAND

- A. Aorangi Mine area.
- B. Blenheim.
- C. Christchurch.
- Co. Collingwood.
- D. Dunedin.
- G. Greymouth.
- H. Hukitika.
- I. Invercargill.
- L.M. Lake Manapouri.
- L.T. Lake Te Anau.
- L.W. Lake Wakatipu.
- N. Nelson.
- O. Oamaru.
- P.I. Preservation Inlet.
- W. Waimangaroa.

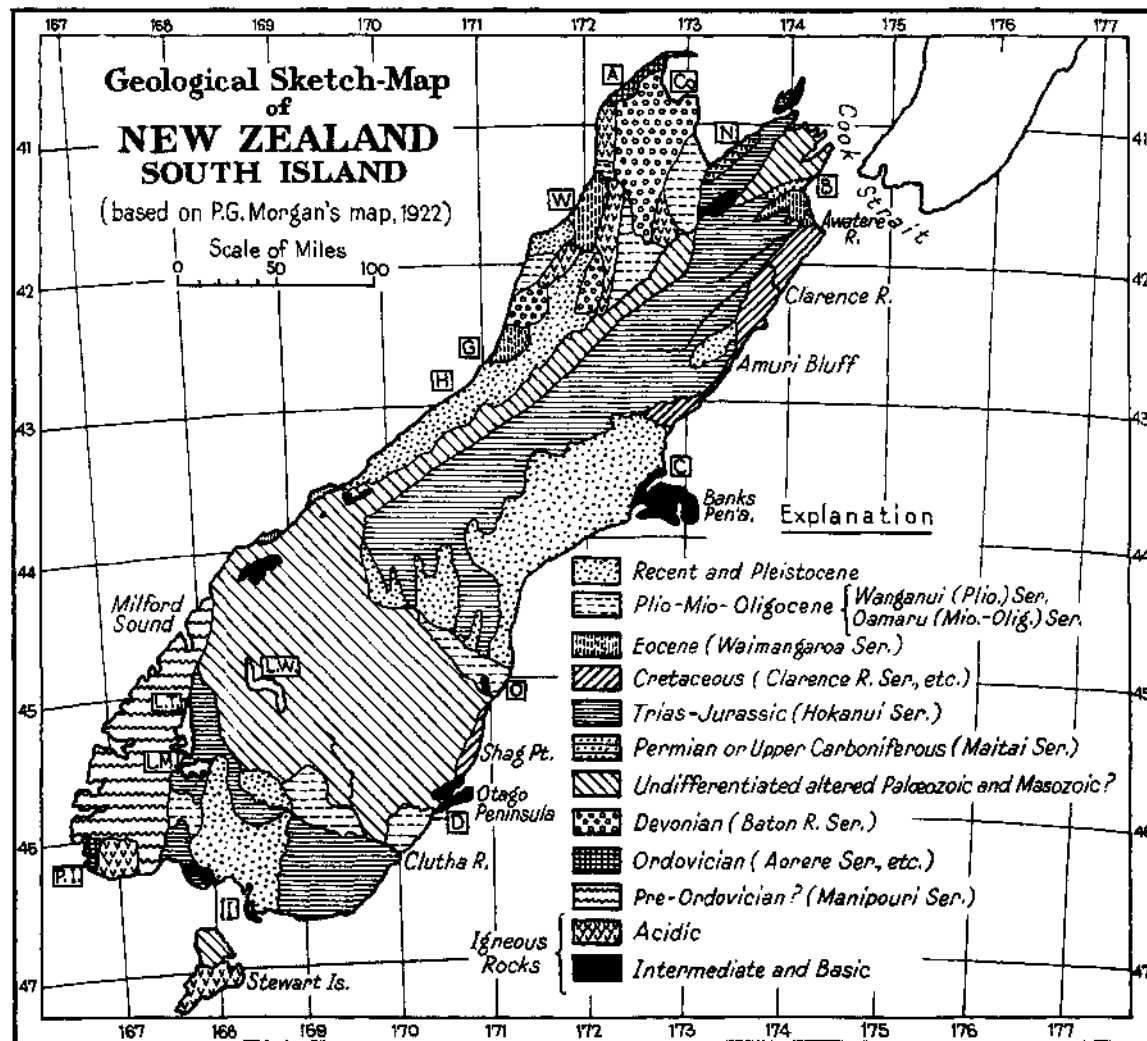
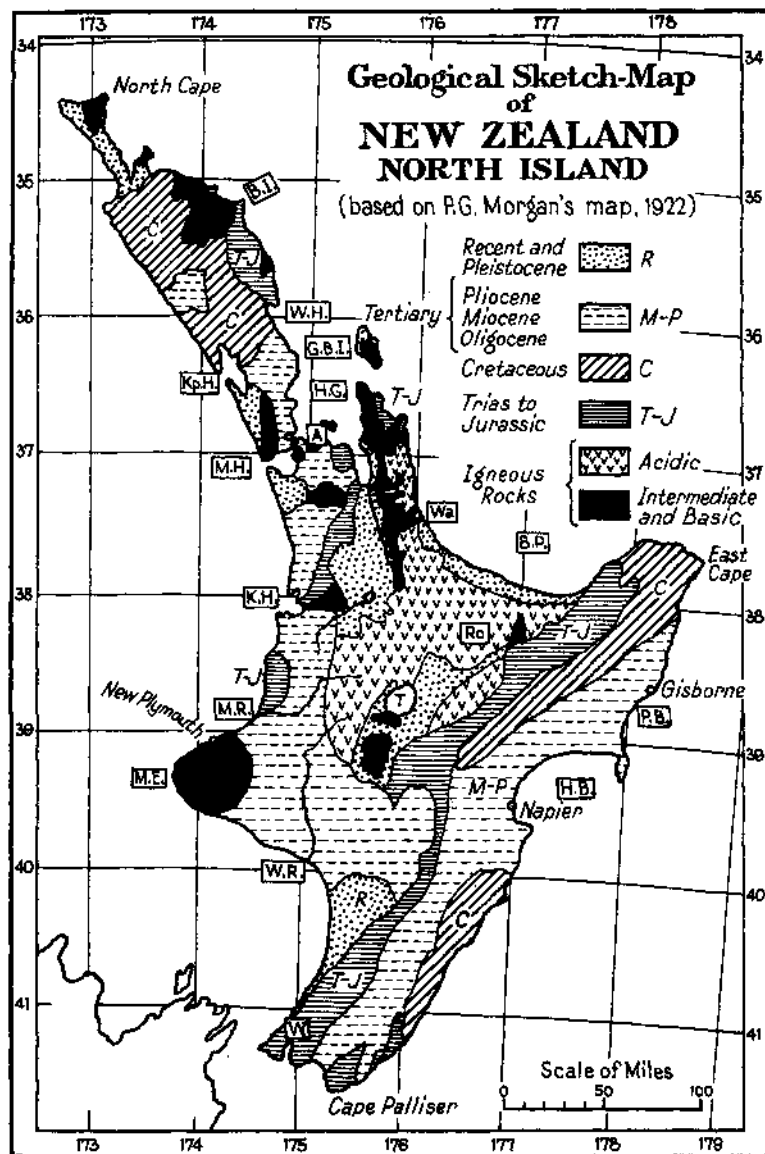


Fig. 25

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CHAPTER XV

OCEANIA

SECTION I.—BRITISH NEW GUINEA (PAPUA)

General Characters and Relations^{12 25 26}.—Owing to our geological knowledge of New Guinea being very incomplete, only a bare outline of the structure, with certain disconnected details, can be given at present^{1-5 9 12 16 24}. New Guinea lies on the continental shelf enclosed by the 100-fathom line and is thus connected with Australia⁴¹.

Contrary to the Australian continent, where there has been no true folding since the close of Palaeozoic time, the folding along the arc traversing New Guinea took place in post-Cretaceous and Tertiary times³⁴. Ancient crystalline and metamorphic rocks form the core of the Cordillera which traverses the island and rises in a long lofty range or series of ranges running its whole length from north-west to south-east, with heights of over 15,000 ft. and thus constituting the backbone of British New Guinea. It seems to be largely of the nature of a horst with its precipitous sides due to gigantic faults.

The relations of the tectonic lines⁴⁴ of New Guinea to those in the East Indian Islands³⁶ are variously interpreted, though their longitudinal and parallel trend through the greater part of the length of New Guinea is recognised. Benson³⁹, Stanley^{33 38}, Gregory²⁵, Andrews⁴¹, Molengraaff⁴³, David²⁹, and Van Bemmelen⁴⁴ have modified Suess⁴ conclusions as to their course and connection with the great Himalayan-Burmese structural arc. But certain main structural features have been generally established, and there is wide agreement on them. Parallel to the north coast of New Guinea there is a line of folds which runs close to it for about half the length of the island, bending up to pass into the Bismarck Archipelago shortly before reaching the Huon Gulf, and thus crossing over into New Britain³⁴. The central range of the island constitutes part of Suess' 'First Australian arc,' but, according to Stanley³³, it forks towards its eastern end and one branch passes over into the D'Entrecasteaux and Louisiade islands. Its western end may be prolonged into the islands of Ceram and Buru, as Suess⁴ and others have supposed, but at any rate the trend-lines of the folds are here much complicated and apparently bent and twisted, and their connection with the Banda arc and Burmo-Malayan trend-line is

doubtful²⁵. Between the north coastal range and the Central Cordillera there is a long depressed faulted zone or rift valley bounded by faults and extending 1200 miles parallel to the coast from the MacCluer Gulf eastwards. The main faults or thrust-planes affecting the whole island are longitudinal, following the trend-lines of the Australian arcs^{34 41 44}. The great trough- and block-faulting began in Cretaceous times, but continued mainly throughout Tertiary times.

It does not appear proved that the main axial line from Java, Sumatra, and Timor is directly continued into New Guinea, but there seems to be an overlapping syntaxis or *en Echelon* arrangement of structural lines in the region beyond its western extremity³³. However, the Timor line may have been bent into a north-easterly direction by the resistance of the great crystalline *massif* of Darwin and Arnheni Land. The trend-lines of New Guinea belong to the same series of lines as those which pass through Burma, the Malay Peninsula, Java, and Sumatra, and the date of the folding also was apparently synchronous with that of these regions—in fact forming an integral part of the same extended set of movements which lasted into the late Pliocene times. The chief elevation of the New Guinea Cordillera took place in post-Miocene times, for the representatives of the Miocene Burdigalian beds were raised to a height of 16,000 ft., and no later beds have been deposited upon them²⁹.

The south-east peninsula of New Guinea contains the ultimate prolongation of the main axial cordillera, but it also has various volcanic rocks of probably more than one period on each side of it (showing at least one active vent). More or less disturbed Tertiary rocks on the south side form the hilly country. The coastal region and foot-hills on the south side, extending inland from the Gulf of Papua for 50-60 miles, form a peneplain which has been cut across the folded Miocene and Pliocene beds, and covered in places by streams of post-Pliocene lavas and beds of tuff. The presence of Recent coral limestones on these volcanics and on the Pliocene rocks up to heights of 1000 ft. shows a Recent submergence of this part of the island followed by an upheaval.

The whole of the plateau in the interior of the Western Division consists of jagged masses of upraised limestone beds worn into swallow-holes and traversed by underground rivers. In a few places intrusive basalt pierces the limestones. The age of all these beds is uncertain, but many are Tertiary (see below). The main range is believed to be largely composed of volcanic rocks, judging from the pebbles in the river beds¹⁷. Much older rocks (? Palaeozoic) occur towards the west end of the plateau.

The extreme western part of British New Guinea is little known,

but Jurassic, Cretaceous, and Eocene fossils²⁹ have been collected on the Fly River or its tributaries. Eocene marine limestones are present some distance up the Fly River, while Miocene deposits, which occasionally contain coal-seams and petroleum, are of much importance in the lower country.

The East Australian Cordillera of ancient rocks, which runs up from Tasmania along the eastern side of the Australian continent not far from the coast and reaches Cape York Peninsula in the north, appears to cross the Torres Straits (where it is represented by the western islands) and to enter British New Guinea, its termination being apparently situated on the margin of the great alluvial plain in the granite hill of Mabudaun in Daudai, thus meeting the New Guinea Cordillera at a considerable angle. There are also minor folds and faults crossing the main trend-lines of the island, and running in a general meridional direction.

The **Louisiade Archipelago**^{23 30}, which lies at the eastern end of New Guinea, is a continuation of one branch of the main axial chain of that island, lying on Suess' 'First Australian arc' (inner line). One at least of the islands rises to a height of over 3000 ft. The island of Misima (St. Aignan)³⁰ at the extreme north-eastern end of the Louisiade Archipelago²³ has a basal metamorphic series of rocks of both sedimentary and igneous origin, including gneisses of various types, schists, crystalline limestone, etc. These are penetrated by intrusive dykes of porphyry and porphyrites, and in places by masses of gabbro. Quartz veins and lodes are associated with the limestones, carrying gold, silver, and sulphides of zinc, lead, copper, and iron. There are also late-Tertiary sedimentary rocks (sandstones⁴, mudstones, with bands of limestone, grits, and conglomerates) containing lamellibranchs, foraminifera, and plant-remains, and, interstratified with these beds there are volcanic breccias, lavas (trachytes), and tuffs. Coral reefs are extensively developed²³ and, according to Davis²³, their relations strongly support Darwin's theory rather than that of glacial-control.

Fergusson Island⁴⁰, of the **D'Entrecasteaux Group**, has had its geology investigated by Stanley. Nearly half its area is occupied by metamorphic rocks, some of sedimentary and others of igneous origin, and they have been intruded by doleritic dykes and other rocks. Gneisses, hornblende-schists, mica-schists, and quartz-schists compose this old series. Some granitic intrusions are also present. There is a large development of late-Tertiary to Recent volcanic rocks, including andesites, basalts, trachytes, rhyolites, etc. Many solfataras and fumaroles exist, and there are also thermal springs and geysers, the volcanoes being apparently in many cases only dormant. On Normanby Island folded Miocene limestone

occurs, but the age of the raised coral limestone on Fergusson Island has not been determined. Gold-bearing quartz occurs in Sudest in vertical clay-slates.

DETAILS OF THE FORMATIONS

Archæan, Pre-Cambrian ? and Palæozoic—The crystalline and metamorphic rocks of the Owen Stanley Range in the south-east portion of the island consist chiefly of steeply-folded schists, with clay-slates and some granitic masses. Quartz-mica-schists, talc-schists, and chlorite-schists have been described from various parts of the Cordillera, and they are invaded by granites, diorites, and gabbros. Stanley⁸⁸ recognises several series of rocks in these Pre-Cambrian formations. The schists are occasionally auriferous, and it is from them that the alluvial gold has been originally derived. In several of the Entrecasteaux Islands, as above described, they are associated with granitic gneiss. The islands in Torres Straits, which belong to the East Australian Cordillera, expose masses of similar igneous intrusives (granite, diorite, etc.⁶).

The age of these rocks is uncertain ; some may be altered Lower Palæozoic rocks, or even of later date, while in Dutch New Guinea²⁸ Carboniferous¹⁸ or Permian limestones are known to be developed. The Middle Devonian apparently occurs in Papua, for loose blocks of limestone on the Tauri River contain^{2 29} the coral *Heliolites porosa*.

Near the headwaters of the Kikor River, on the south flank of the central range in the Western Division of the British Territory, fossiliferous limestones, sandstones, mudstones, and conglomerates, with beds of bright hard coal, have been referred to the Carboniferous or Permo-Carboniferous¹⁷, and a possible specimen of the Lower Gondwana fern, *Glossopteris*, has been recognised in southern New Guinea in the coal beds and sandstones on the western tributaries of the Upper Purari River¹⁸.

Mesozoic¹⁵.—Jurassic Ammonites^{5 9} belonging to the genera *Kepplerites* and *Stephanoceras*, and allied to the European Upper Oolite (Cafiovia) species *K. calloviensis*, and to *St. coronatum* and *St. blagdeni*, have been found in pebbles on the Strickland and Fly Rivers in 142° E. long. Farther west, in Dutch New Guinea⁷, four well-marked Jurassic horizons, including beds equivalent to the Callovian, and containing ammonites, are known to occur. Jurassic beds of the same type, and with identical fossils, occur in the Sula Islands near Celebes. In the northern part of Dutch New Guinea traces of the fauna of the Spiti Shales of the Himalayas have been found¹⁸.

Cretaceous beds are also present in British territory on the Strickland and Fly Rivers, judging from the discovery of the Cenomanian ammonite genus *Acanthoceras* and of a species of *Inoceramus* or *Aucella*, as well as of two species of coral¹ of the genus *Actinacis* in pebbles of chert¹¹, one species being also found in the Cretaceous of Sumatra. In Mandated New Guinea Cretaceous (Senonian) rocks much folded and disturbed on the north coast, and with interbedded andesites, have been described, the limestones amongst them yielding marine fossils⁸ (see below).

Tertiary.—There is a great similarity between the Tertiary foraminiferal, coral, and molluscan faunas and those of the Dutch East Indies ; the sequence appears to be the same, and the same terminology is tentatively applied⁸⁷. It is by means of the foraminifera that this correspondence has been mainly established.

Eocene.—The lowest Tertiary beds in Papua are referred to the Middle Eocene and consist of coral limestones and cherts on the Upper Fly, Palmer

and Black Rivers. A considerable number of corals considered to be of Eocene age, and belonging to the genera *Stylophora*, *Stylina*, *Leptoria*, *Plesiastrea*, *Porites*, *Montipora*, etc., have been described by Gregory¹¹ from limestone pebbles on the Fly River. Foraminiferal limestones also occur in this district of Middle Eocene^{16 20 87} age, while in the neighbouring parts of Dutch¹⁸ and Mandated¹⁴ New Guinea similar limestones^{16 22} often form lofty precipices, and occur in thick beds which have yielded the characteristic Eocene genera *Nummulites* and *Alveolina*.

In the south-eastern part of New Guinea there is a limestone and shale series fringing a great part of the coast from Caution Bay to McFarlane Harbour, known as the *Port Moresby Series*. The beds are usually steeply up-turned or folded, and some contain large concretions of flint or chalcedony up to several feet in diameter, or have bands of chert interbedded. In Hall Sound in the Mekeo district (long. 146° 35' E.), they have yielded radiolaria, foraminifera, and numerous marine mollusca (*Conus*, *Turritella*, *Cardita*, etc.) unlike those of the Tertiary of Australia. These beds form a broad coastal band from Redscar Bay to Round Head, where they extend into the interior. Chapman²¹ considers them to be pre-Miocene. Farther to the south-east (long. 149° 30' E.), on the coast, the limestones with flint nodules, but without fossils, termed the Boioro Limestones, may belong to the same series. The Lower Port Moresby beds are put by David²⁹ in the Upper Cretaceous, but the Upper beds in the Eocene.

The intense folding of the Port Moresby Beds points to a special set of orogenic movements which took place prior to the outpouring of the lavas which are described below.

Oligocene and Miocene.—The oil-bearing strata^{19 27 31 33} are usually referred to the Miocene. They consist of fresh-water deposits alternating with marine limestones containing foraminifera, such as *Orbitoides* (*Lepidocyclina*), etc. The limestone of Bootless Inlet to the east of Port Moresby, which is composed chiefly of the tests of *Lepidocyclina*, and is of Lower Miocene age, is an example. The chief area of these beds is situated west of Port Moresby in the neighbourhood of the Vailala²⁷ and Purari Rivers.

The same petroliferous province embraces the Dutch East Indies, Java, Sumatra, and Borneo, and probably Burma.

The petroliferous beds in the Upoia district¹⁹ are classified as follows:—

v . . . q . Grits, sandstones, blue marls, etc., with many plant-remains and a coal-seam at base.

Upoia Beds S ^P Petroliferous mudstones, sandstones and thin unfossiliferous limestones.

Fossils are locally abundant in these Miocene beds (as, for example, at Vaiviri). Calcareous algæ (*Lithothamnion*) occur and numerous Recent genera of mollusca. The oil comes from the mudstones, sandstones, and thin limestones of the Upoia Group, and collects along the anticlines, the axes of which are also marked by mud-volcanoes and gas-vents. The whole series in this district has suffered two periods of folding, one in post-Miocene times, which formed folds trending north and south, and the other in post-Pleistocene times, which produced folds at right angles to the former set, and are of importance in connection with the occurrence of the petroleum. In the Hororo district⁸¹ limestones, sandstones, and mudstones with thin coal-seams constitute the petroliferous strata²², and are of Middle or Upper Miocene age²⁷. They are highly fossiliferous⁸², and contain here and in parts of the oil-field numerous mollusca and foraminifera³². The Upper Miocene beds cover the greater part of the country in the vicinity of the Vailala River²². All the Miocene beds are intensely folded by an early north and south movement, and by a

much later, probably Recent, east and west folding, the Pleistocene beds being tilted on an east and west axis and resting on the Miocene beds striking north and south.

Seams of brown coal, some as much as 2 ft. 9 in. thick, occur in the Miocene succession in various parts of the country, and in Dutch New Guinea fossiliferous coal-bearing Miocene beds are also known.

Of **Pliocene** or **Pleistocene** age there are the sandstones, grits, and conglomerates of the Kivori district north-west of Hall Sound⁹. Their outcrop runs parallel to that of the Port Moresby beds, and they form the low range of the Kivori Hills. The beds are horizontal, or dip slightly to the north. Certain fossiliferous limestones, grits, etc., at Cape Possession, containing a large percentage of marine mollusca still living in the neighbouring seas, are referred by Chapman²¹²⁷ to the Pliocene. The Pliocene beds are of various types, and comprise marine fossiliferous³² marls, clays and sandstones, with some limestones and brown coal.

Massive coral limestones of Pleistocene or late Pliocene age are also known, which belong to the period of Recent submergence, and there are also fossiliferous Pleistocene marine clays and foraminiferal oozes¹⁴, indicating a later period of elevation.

Post-Tertiary or Recent volcanic rocks are largely developed in the south-east part of the island on the peneplain which has been produced on the folded Port Moresby beds. Andesitic, trachytic, and rhyolitic lavas, tuffs, and breccias are represented. Many large lava-flows spread over the country, from Mount Yule, Mount Obree, Mount Dayman, and Mount Victory, on both sides⁸ of the Owen Stanley Range. Two volcanic zones seem to be present, one forming the Aird Hills about 200 miles north of Port Moresby, but lying on the south side of the central range, and the other, including Mount Dayman and Mount Victory, situated on the north side of the same range. This northern belt of volcanoes extends²⁹ in Papua from the Mambare River to beyond these two mountains, and is continued in the Louisiade' and D'Entrecasteaux groups of islands, where a solfataric state of activity still exists. Misima Island³⁰, off the east end of New Guinea, possesses thin flows of trachyte. The Murray Islands have basaltic lava-flows with great stratified ash-beds containing blocks of coral and foraminiferal limestone; many of the islands are stated to be relics of old craters. The Boioro Limestones are pierced by intrusive dykes of dolerite belonging to some stage of this late Tertiary or post-Tertiary period of vulcanicity.

In Torres Straits some of the eastern islands are of Recent volcanic origin. Woodlark Island (Murua) is worthy of mention because the igneous rocks of which it is composed carry gold and some galena¹⁰.

Some of the volcanoes in the northern belt (*e.g.* Mount Victory) appear to be still active or only temporarily dormant, and to lie on one of the chief fracture-zones which were formed in late Pliocene or Pleistocene times.

The latest crustal-movements, which are shown by the raised coral limestone reefs spread over the lavas of the south-eastern peneplain, have caused the emergence of the land to the extent of 1000 ft. on the northern coast, and of over 2000 ft. on the southern coast¹² without any folding of the rocks. All gradations have been observed, from reefs raised only a few feet above the water up to those elevated this great height.

The geological history of this part of the earth's surface bears close relations to the existing fauna and flora of Malaysia⁴² and Australia. It seems that the whole group of islands between south-east Asia and Australia were subject in Cretaceous or early Tertiary times to much instability, and hydrographic maps⁴⁸ show many deep troughs and basins between the islands. New Guinea seems to have been alternately connected and disconnected with Australia

during Pleistocene times. But the break between Australia and Asia took place first, and probably in late Cretaceous or early Tertiary times.

ECONOMIC GEOLOGY

The alluvial **gold** which is found in the gravels of many of the rivers⁹ has been derived from the old crystalline schists and other metamorphic rocks, and gold-bearing quartz-veins are found in schists and slates of the main chain. The chief auriferous deposits are situated in the Mandated Territory, but, as above mentioned, gold-bearing quartz-reefs occur on Woodlark Island¹⁰ and on the island of Misima^{23 30}; these are connected with the igneous intrusions in the Pre-Cambrian schists and gneisses. Argentiferous galena and zinc-blende are found on the same islands. Alluvial platinum and osmiridium derived from ultrabasic rocks are known in fluvial deposits; these come from the serpentine of the rift valley north of the Central Cordillera. **Copper**, associated with the gabbro at Laloki, is worked. **Oil**^{19 22 31}, as above stated, has been struck in the Miocene beds as well as brown coal, and fragments of coal have been obtained from the Purari River (Cretaceous) beds, though no workable coal-seams are known.

Further details of the mineral resources are given in the description of the Mandated Territory.

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SECTION II.—MANDATED NEW GUINEA
(FORMER KAISER WILHELMSLAND)

Relationships.—Much of what has been above written about the geology of British New Guinea applies naturally to the Mandated Territory which adjoins it, but certain parts of the Territory have been specially investigated and appear to have a somewhat different or local development of rocks. The general structure of the whole island and its relations to neighbouring lands have been already described.

General Structure and Characters^{3 7 11 23-25}.—Our existing knowledge of this region is still incomplete and disconnected. There is a basement of old crystalline igneous²² and metamorphosed sedimentary rocks exposed in various places on or near the coast, but particularly in the mountain ranges, and pebbles of these and other rocks which are not known *in situ* occur in many river-gravels. These ancient rocks form part of the great central axis of the island. From Astrolabe Bay gneiss, mica-schist, and quartz-schist have been recorded, but many of these rocks are metamorphosed Tertiaries, and the Parsee Peninsula consists of granite. Gneiss has been stated to occur in the Bismarck Mountains, which form the principal chain of New Guinea, and one of the foot-hills of this range consists of gabbro and peridotite. In the Waria Province², Hercules River, rocks of a diabasic or dioritic nature carrying gold are described as resting in places on granite. The occurrence of quartz-diorite, pegmatites, diorite-porphyrity, olivine- and hornblende-gabbro, quartz-keratophyre and granite²² is proved by the pebbles of river-gravels, or they have been noted as huge boulders in a steeply-dipping conglomerate of unknown age in the Orzen Mountains, and farther north on the Nuru River. The Hunstein Mountains on the Kaiserin Augusta (Sepik) River consist of clay-slates and mica-schists striking east and west, and old igneous rocks, including granite-porphyrity, diorite²², etc., form the culminating peaks. To the south of these mountains gneiss, clay-slates, quartzites, etc., occur nearer the Central Range⁴. It is in this basal complex that auriferous veins occur on Edie Creek^{11 20} in the Bulolo gold-field west of Huon Gulf, associated with quartz-porphyrity intrusions¹⁰, and here are the principal gold-fields. The rock-types^{12 20} into which these intrusions have entered are described as slates, shales, phyllites, limestones, and 'mudstones' which are probably soft altered schists. All the beds are much contorted. These basement rocks have been termed the *Kaindi Series* and are

widely spread in the Morobe and other areas ; they are supposed to be pre-Mesozoic in age²⁰, but this is doubtful, though they are at any rate partly pre-Tertiary, being invaded by intrusions of Tertiary porphyry²⁰. Their metasomatism²⁶ is associated with the Tertiary mineralisation.

The oldest rocks of which the stratigraphical age is determinable consist of limestones, calcareous sandy or shaly marls, and sandstones in the Torricelli Mountains. These beds dip at 80°-85° N.N.W. and rest on andesite, and the same beds seem to occur in the Finisterre Mountains, where the limestones are much developed, as on Mount Tiktaknan ; farther to the west and between these mountains and Mount Wilhelmina Peak (15,420 ft.) the divide is formed of Cretaceous limestone. Pebbles of these sedimentary rocks are found in the river-gravels, and have yielded fossils which are considered to indicate an Upper Cretaceous (Senonian) age. The mollusca³ include *Cardium productum* Sow., *C. reiberi* Richarz, *Venus eiloensis* Rich., *Tapes constantini* Rich., *Psammosolen arnoldi* Rich., and *Cerithium* cf. *sociale* Zek., the new species being mostly allied to Gosau forms. Foraminifera, corals, and *Lithoihamnium* also are abundant, but these fossils afford less satisfactory evidence of the age of the beds and suggest rather the Oligocene or Miocene. It is, however, concluded, on the evidence of the mollusca, that the beds partly belong to the Senonian, and are part of the same Cretaceous series which occurs in Borneo, Buru, and Misol. The connection with the Upper Cretaceous of South India is limited to the occurrence of *Cardium productum*. In the Bismarck Mountains a species of *Cerithium* has been found which seems to indicate the presence of Cretaceous beds here also. It may be suspected that the Lower Cretaceous and Jurassic formations which are known to be developed in Dutch New Guinea⁶ on the west extend eastwards into the Mandated area, but they have not yet been definitely proved. It appears probable from these disconnected observations that the Cretaceous marine transgression extended over nearly the whole of the island.

The next younger series of rocks consists of marine sediments, comprising yellowish loam and bluish clay, often of an arenaceous character, and full of foraminifera ; a species of *Terebratula* and several bivalves have also been recorded from them. These beds, which have a wide extent, are horizontal near the coast, but farther inland³ become inclined and ultimately dip as much as 20° E.S.E., rising to higher levels and forming hills behind the coral-limestone hills near Berlinhaven. The brown coal found in the neighbourhood of Astrolabe Bay is also probably of Tertiary age, as in Dutch New Guinea and in the Upoia district in Papua. Some of these beds are now proved to be of Tertiary age by their fossil contents.

The *Lower Aitape Series*, composed of tuffaceous foraminiferal limestones with contemporaneous basalts, andesites, felsites, and rolled pebbles of serpentine, is Oligocene-Miocene in age. At its base there is a conglomerate containing pebbles of an Eocene nummulitic limestone. The formation is about 3500 ft. thick and is rich in species of *Lepidocyclus* in the Oligocene part, but *Miogypsina* and *Amphistegina* mark the Middle Miocene.

The *Astrolabe-Kemp Welch Series*⁷ consists of sericitic slates and schists interstratified with indurated Globigerina limestone together with lavas and agglomerates. It has been invaded and in places metamorphosed⁷ by a mass of gabbro with which copper ores are associated. The limestone is probably Burdigalian in age.

The *Ouba-Mena Series* at Madang, which ranges in age from Lower Miocene to Pliocene, is estimated to be 13,000 ft. thick, but there are probably unconformities in it. It has massive conglomerates at its base passing up into Globigerina marls with *Lepidocyclus* and *Miogypsina*. Sandstones with thin coal-seams succeed it. These beds seem to correspond with the *Astrolabe-Kemp Welch Series* and the *Upper Aitape Series*, which is supposed to be Middle and Upper Miocene, and has abundant *Oligobryozoa*. It consists of sandstones, marls, and limestones.

Beds of Pliocene age include the *Lower Wanimo Series* and especially the *Finsch Coast Series* north of the Huon Gulf. These are rich in marine fossils and seem to be the chief petroliferous beds. Some of the foraminiferal limestones¹³ are of Pliocene or Pleistocene age, while others are Recent. The Pleistocene beds (*Yalingi Series*), consisting largely of conglomerates, rest on the folded and eroded Finsch Coast Series, and include sandy clays and mudstones. The *Upper Wanimo Series* is probably Pleistocene also, and consists of lignitic and foraminiferal clays.

Coral-reefs and coral-limestones of late Tertiary or Recent date are characteristic features of the north coast, and the raised reefs³ indicate two or three movements of elevation in Recent times¹¹. The raised terraces or coral platforms are most developed on the MacLay Coast, rising to heights of 400-500 ft. and forming three or four broad horizontal platforms at different levels sharply separated from each other. In the mountains near Finschhafen coral limestone, sands, and mud are found up to heights of 400 metres. On the coast some of the reefs are only slightly elevated, one on the island of Tumlec in Berlinhafen being only 21 metres above sea-level.

Volcanic phenomena are limited to the fringe of the numerous small islands lying along the coast, and the chain of volcanoes bends off in an arc towards New Britain^{3 15}, and is continued along the inner curve of the north coast of this island up to Rabaul, in New Britain. Some of the volcanoes are only recently extinct, while

others are in a solfataric stage^{16a 24}. In the eastern members of this chain volcanic eruptions¹⁶⁰ are still a feature. Most of the active volcanoes lie along fault lines. Towards the western part of the territory, on the other hand, there are no active vents. In Berlinhaven and on the neighbouring island of Tumlec masses of coarse andesitic breccia point to the existence of one or more former centres of eruption. The lavas which sometimes break through the coral limestones, but more generally overlie them, consist of pyroxene-andesites, hypersthene-andesites, and olivine-andesites. The Finisterre Range is stated to be largely composed of Recent volcanic rocks (such as augite-andesite), as well as Cretaceous and other limestones²⁴.

The chief tectonic events took place as in the rest of New Guinea^{14 21} in post-Miocene times, and the folding of the strata and determination of the main trend-lines correspond with those of the first Australian and Banda arcs. The most important fault is the Carstensz east-and-west fault which begins in Dutch New Guinea, and probably extends to the Sepik Valley and beyond into Papua. Minor parallel faults or thrust-planes have been developed with the same trend on both north and south sides of the Cordillera.

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Gold^{10 12 18 20 26}.—It is in the metamorphic rocks of the Cordillera and in the alluvial¹² deposits of the valleys that this mineral is being worked, especially in the Morobe district¹⁸. In the Day Dawn Mine²⁰ in that district the ore-body occurs in phyllites (Kaindi Series) invaded by quartz-porphyry; the gold, associated with silver, occurs in quartz-veins or along zones of Assuring. The mineralisation is considered to be of Tertiary age²⁶.

Oil.—The chief horizons for oil are in the Finsch Coast Series and Lower Wanimo Series (of Pliocene age) in the Mandated Territory, and in the lignite-bearing beds, calcareous grits and sandstones of the Vailala and Purari River areas of the Gulf region³⁹ in Papua.

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SECTION III.—BISMARCK ARCHIPELAGO

This group of islands lies on the outer line of Suess' 'First Australian arc' on which he placed also the Solomon Islands and New Hebrides.

New Britain^{1-3 5 13 14 16 17 23 24} is a long narrow island with a peculiar curved form concave towards the north-west, and it stretches from 4° 6' to 6° 30' S. lat., and from 148° 20' to 152° 25' E. long. Its interior is practically unknown. The island seems chiefly composed of volcanic rocks of Tertiary and later date, and these build up the mountainous districts. But older rocks occur in the Gazelle Peninsula¹¹ at its north end⁵ (see below). There is said to be a core of schists and gneisses into which granodiorites and other igneous rocks have been intruded. Associated are supposed *Cretaceous* limestones (see below). The next beds in age are steeply-dipping *Miocene* sediments, and on them rest unconformably gently-folded foraminiferal deposits and tuffs referable to the *Pliocene*. There is evidence of recent elevation along the coasts¹⁸ of the whole area. A series of volcanoes, many of them still active¹⁹, extends along the curve of its north coast, and this line is continued westward¹⁶ into New Guinea by a chain of islands of a volcanic nature. One group of volcanoes at the north-east end of New Britain rises to a height of 1200 metres, and well-preserved cones and craters, often of large size, are conspicuous objects along the coast. The volcanic materials comprise bedded ashes and tuffs, with dacites, liparites, andesites, and basalts^{13 14 19}. The andesites are the most abundant lavas. The eruptions commenced and reached their maximum in the Tertiary period. According to Stanley²⁰ there were three chief epochs of vulcanicity and earth-movements. Of these the first was associated with the chief zones of faulting which were more or less parallel to the axis of folding. The second phase coincided with strand-folding and coastal fractures, while the third phase was partly connected with a series of north-and-south rifts more or less at right angles to the coast-line. This latest and recent²⁴ outbreak of volcanic activity is that developed as above mentioned along the northern coast of New Britain¹⁹ and stretches up from the Mandated Territory of New Guinea. Sedimentary rocks (sandstones, brown coal, etc.) of Tertiary age occur in the Gazelle Peninsula¹¹.

There are also older igneous rocks in the Baining Mountains which rise to a height of about 1500 metres in the Gazelle Peninsula^{11 u}; they include gabbro monzonite, gabbro, diorite, diorite-porphyrite, and augite-porphyrite. Below the main range of the

Baining Mountains there is a lower line of hills composed of white crystalline limestone rising to heights of 525 metres and much weathered into gorges, caverns, and underground water-courses. From this limestone a specimen of *Actceonella* has been obtained, and from this fossil and the character of the rocks it is believed that the beds are of Cretaceous age and belong to the same series as those in New Guinea. Liversidge¹ has described a soft 'Cretaceous' limestone full of foraminifera, but these are said to belong to South Atlantic Recent deep-sea species, so that the geological age of the rock is open to doubt. Coral-reefs of recent origin, some of them raised above sea-level, occur along the coast and on the neighbouring islands.

The French or Le Maire Islands, lying between 149° and 150° E. long, and about 50-60 miles north of New Britain, show well-preserved volcanic cones and craters. One of the latter, breached by the sea and forming a semicircular harbour, consists of massive lavas of a basaltic character and beds of tuff. Lottin Island is a volcanic cone 5200 ft. high, and Volcano Island in its vicinity is of the same nature and rises 3500 ft.

New Ireland seems to be a northern continuation of the same curved line of islands as New Britain, but bends to the north-west. The southern part is volcanic, but the elongated north-western portion is composed of a ridge of sedimentary rocks resting on an older basement, as in New Britain¹⁶, and represents the most easterly of the folds which run parallel to New Guinea. Porphyry, diorite, and a grey crystalline limestone, at a height of over 2200 ft., have been recorded by Liversidge. Probably these rocks belong to the same series as those above described from the Gazelle Peninsula of New Britain, and a similar limestone is stated to occur in the Solomon Islands. According to Schubert^{12 17} there are Nummulitic and Lithothamnium limestones of Lower Oligocene age. The *Lepidocyclus* Limestones are attributable to the Lower Miocene, but the Middle Miocene beds contain no *Lepidocyclus*. Many of the *Globigerina* deposits are of Upper Miocene age, but there are also *Globigerina* tuffs and calcareous deposits of Pliocene age¹⁶ as in New Britain. Some *Globigerina* limestones, containing species said to be like those in the neighbouring deep sea at a depth of 6000-9000 ft., are found at a height of over 3000 ft., indicating a recent upheaval of the island^{16 18}. Miocene and later foraminiferal limestones are widely developed¹². According to Suess and Stanley¹⁶, New Ireland²¹ is a continuation of the Solomon Islands, and the chain is prolonged by the Santa Cruz and New Hebrides Groups, forming an arc slightly convex to the north-east (see p. 689),

New Hanover is apparently composed of the same rocks as New Ireland, with a nucleus of older and younger igneous rocks, and with Tertiary marls resting on them in the north.

The **Admiralty**^{6 7} and other smaller islands in the Bismarck Archipelago are chiefly composed of recent volcanic rocks and coral limestones. But from the island of Lou a microgranite has been described⁹. Basaltic lava-flows, with some ashes, pumice, and obsidian^{8 9}, have also been observed, and in several places craters and hot springs exist. These Admiralty Islands form the continuation of the arc which includes New Hanover and New Ireland²¹. The geographical distribution of the volcanoes in the whole Bismarck Archipelago shows the existence of more than one line along which the vents are arranged¹⁰.

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SECTION IV.—SOLOMON, FIJI, TONGA, AND
OTHER ISLANDS IN THE PACIFIC OCEAN

General Characters and Relations.—The structural relationships and geological history of the islands²³ in the Pacific Ocean are still incompletely known, but the islands are not scattered about promiscuously or without any order or plan⁴ 3849 50 54 56 57 67, and Dana long ago recognised that the truly oceanic islands are arranged in more or less straight or gently-curved parallel linear series, forming long chains trending about north-west to south-east, with the exception of one series from New Zealand to the Tonga Islands which runs N.N.E.-S.S.W. These probably represent lines of fracture, along which volcanoes²⁴ have been built up, or possibly they indicate the crests of folds in the sub-oceanic crust^{23 50 54}. Gregory⁵⁴ long ago classified the islands in the Pacific into eight festoons and three chains, and held that the linear arrangement of the islands was due to a series of ridge-folds broken across by subsidence along fractures. Certain of the islands in the south-west part of the ocean (*e.g.* Lord Howe Island) must be regarded as belonging to the broken-up and foundered mass of Australasia of which they form the outlying fragments^{23 73}. The shattering and disintegration of this continental mass apparently took place in late Mesozoic times. Such fragments also include the British groups of the Solomon, Fiji, Tonga, and Kermadec Islands. Many of the islands are entirely of a volcanic nature, and Phillips²⁴ has recognised three main lines or belts of volcanic activity which appear to have a structural significance.

Suess³ was of the opinion that the Australian Archipelago, which is bounded on the north-west and east by the greatest ocean-deeps yet sounded (*i.e.* over 9000 metres), is divisible into three arcs, of which the first and innermost runs from New Guinea⁴⁶ into the north-north-west peninsula of New Zealand, and corresponds with Phillips'²⁴ 'Second line of volcanic activity'; the second is formed by the Caroline, Marshall, Gilbert, Ellice, and Fiji Islands (in front of which line at its western end is the Guam^{1 50} deep), while the third arc, which in a general way agrees with the north part of Phillips' 'First line of volcanic activity,' runs almost in a straight line from north-east New Zealand through the Kermadec and Tonga Groups and perhaps into Samoa. To the east of this third line lies the great eastern ocean-deep. The first arc consists of two concentric adjacent sub-arcs, of which New Guinea, the Louisiades, New Caledonia, and New Zealand form the inner one, while New Britain, New Ireland, the Solomon Islands⁴⁵, and the New Hebrides³⁹ form

the other and outer one⁴⁶. The plan of the arcs shows a virgation proceeding from New Zealand and opening out towards the north-west and west, with the convexities directed towards the north-east or east. The ocean-deeps seem to be of the nature of fore-deeps. The fullest and most recent survey of the relations of all the islands in the south-west Pacific has been given by Hobbs⁸⁰, who recognises several arcuate series of islands along mountain folds on the edge of fore-deeps, and a more northern series of groups consisting of fault-blocks. Andesitic igneous rocks are specially developed in the arcuate series, but basalts in the fault-block islands. Chubb⁵⁰ has recently discussed the structure of the Pacific basin and pointed out that two-thirds of the floor lie at an average depth of 5500 metres and that from it rise a number of ridges trending N.W.-S.E. near the American coast, W.N.W.-E.S.E. over the central parts, but nearly W.-E. near the western margin. Some reach the surface and bear lines of volcanic islands having the same trend. There are traces of another curving trend-line at right-angles, as indicated by the line of great deeps running S.W.-N.E. and continuing the line of the Tonga-Kermadec trough. The coral island zone forms scattered or linear groups along a broad belt extending across the ocean from W.N.W. to E.S.E., parallel to the general trend of the submerged banks and island-lines, suggesting a tectonic connection and supporting Darwin's theory of a subsiding foundation. But the coral islands south of the equator, between 150° and 170° W. long., are on lines having another trend, from N.N.E. to S.S.W., and these lines continue southward between the Samoan and Cook Islands, suggesting a line of subsidence parallel to the line of great deeps. Further knowledge is required before we can decide the age or origin of these remarkable features.

The nature and formation of the platforms on which the coral islands^{17 50} are built up are still matters of dispute, though Darwin's theory still holds the field^{37 50}. Daly's^{22 37} theory of glacial-control would explain them by the general lowering of the sea-level in tropical seas during the Ice-age, owing to the attraction of the masses of ice at the poles and to the wearing down of the continental margins or scattered pre-existing elevations on the sea-floor to a uniform height by marine erosion. On this hypothesis a subsequent rise in the level of the sea-water on the melting of the ice is necessary to submerge them to the requisite depth. Davis⁶⁰, however, believes that coral reefs are better explained by subsidence and aggradation.

There are certain common features in the lavas of the islands of the Pacific, which have led Daly²¹ to form the view that there is a subcrustal layer of primary basalt beneath the whole Pacific Basin, **and that** from this primary magma the pyroxene-andesites and other lavas have been differentiated. The view that there was an

important difference between the igneous types of the Pacific and Atlantic basins does not meet with general support as there are many exceptions in the character of the lavas, and Gregory⁵⁰ and **others** reject the distinction. A ring of andesitic rock-types forming a zone round the margins of the Pacific and expanding greatly in width to the north-east of Australia embraces all the islands from Japan to New Zealand, as well as the East Indies and Malaya, and is a marked petrographical feature in the distribution of the igneous rocks, whereas the greater part of the basin of the Pacific north of the Equator and south of lat. 20° S. contains nepheline-bearing rocks. The volcanic islands are said to consist of alkaline rocks⁶⁴, and on petrographical grounds^{9 50 51} fall into two main series occurring in distinct zones, the nepheline-bearing and nepheline-free. A third series of islands in which nepheline-bearing rocks are very rare or absent occupy a definite area. The Society and Austral Groups⁵⁹, the Hawaiian, Samoan, and Cook archipelagoes lie in the nepheline-bearing zone. The nepheline-free zone includes the Marquesas, Galapagos, and Easter Island, and these show no linear arrangement. The Marquesas appear to stand at the intersection of two sets of fissures trending N. 7° W. and N. 83° E., making angles of 45° with the trend-lines of the Tuamotu, Society, and Austral groups. Washington⁶³, however, holds that in the intra-Pacific basin the predominant rock-type is basaltic, and that the alkaline lavas only form on 1 or 2 per cent.

(For references see p. 704.)

THE SOLOMON ISLANDS

This group of islands^{1' 27} 34 45 53 55, lying between 5° and 11° S. lat. and 154° and 163° W. long., consists of a double chain of seven or eight large mountainous islands and many smaller ones closely adjoining them. The larger ones have a general trend from north-west to south-east. Only a few of them have been explored geologically. Some are composed mainly of old igneous rocks⁶⁴, others of comparatively recent volcanic materials, and others of calcareous formations of several ages and types. The raised coral reefs, containing corals and molluscan shells, apparently of the same species as those living in the neighbouring seas, are found at heights up to several hundred feet, and indicate successive elevatory movements. Beneath them are foraminiferal and pteropod oozes similar to those from deep soundings in the Pacific, and, according to Guppy, proving an elevation locally of 12,000 ft. in geologically recent times. The volcanic rocks which occur on most of the islands are not all of the same age, but some are of recent date, for volcanic activity is not extinct.

The islands He on the outer line of Suess' First Australian arc ⁶⁷, and belong to a great curved zone of volcanic activity; this zone comprises both the outer and inner lines of this arc, which has a general north-westerly trend. The Banks Islands, Santa Cruz Group, and New Hebrides all belong to this volcanic belt (Phillips' 'Second line of volcanic activity' ²⁴).

The larger British islands in the Solomon Group comprise San Christoval, Maleita, and Guadalcanar, and the ex-German Bougainville, Choiseul, and Isabel, which form the northern part of the chain.

San Christoval, measuring over 70 miles in length and rising 4100 ft. above sea-level, is mainly composed of more or less altered ancient igneous rocks ⁶⁴ comprising (in order of abundance) dolerites, diabases, diorites, gabbros, serpentine, and saussuritic felspar-rock. Ancient sedimentary rocks (quartzite and slate) are also present. The volcanic rocks are basalts. Recent calcareous rocks include a fawn-coloured limestone composed of fine calcareous mud, coral-reef limestones, conglomerates, and finer detrital deposits containing fragments of the underlying rocks. The calcareous formations occur up to a height of 500 ft. above sea-level, indicating recent uplift. Detrital tin, haematite, copper, and arsenic were stated by Guppy ¹ to occur on this island.

The large island of **Guadalcanar**, which has an area of 2500 sq. miles, possesses a variety of plutonic rocks of supposed Cretaceous ⁴⁵ age, including biotite-granite, quartz-diorite, gabbro, and serpentine, and volcanic andesite of later date. Alluvial gold occurs in some of the streams, and manganese and asbestos deposits have also been noted. A limestone (which is possibly of Mesozoic age) has been found on it.

The **Russell Islands** ⁴⁵ at the north end of Guadalcanar have a core of basalt, but are partly covered with coral rock.

The geology of the island of **Maleita** is almost unknown, but olivine gabbro, dolerite, and jaspers have been recorded.

Bougainville ³⁴, 110 miles long by 30 miles wide, seems to possess a nucleus of older eruptive rocks, but the chief mountains are composed mainly of andesite; there are also rhyolites and dacites present upon it to a less extent. Two active volcanoes are known. Mount Balbi is over 10,000 ft. high. Coarse conglomerates and fine tuffs resembling sandstone and containing foraminifera rest on the lavas, and raised coral-limestones indicate a later uplift up to 4000 ft. Rock-fragments from the Orovari River ⁵³ have yielded the foraminifera *Lepidocyclina brouweri*, *L. melanesiana*, *L. sumatrensis*, *Miogypsina mammillata*. etc., which indicate that Lower Miocene

beds are present on the island at the height of 500 ft., as in the Bismarck Archipelago and New Guinea.

Buka³⁴, which lies at the north end of Bougainville, consists of andesites which are covered by tuffs of probably submarine origin. Younger than these are raised coral-limestones.

Choiseul, which is almost unexplored geologically, on the other hand, seems to possess no volcanic peaks, but to consist of foraminiferal and other soft limestones and pteropod oozes.

On the island of **Isabel** serpentine occurs, as well as argillaceous sandstones and a coarse-grained gabbro. Red and green jaspers, chert, and limestone, as on Maleita, have also been found⁴⁵.

The ex-German island of **Fauro**, at the south end of Bougainville, is composed partly of the ancient igneous rocks which occur in San Christoval, and partly of recent volcanic rocks⁶⁴ which include hornblende- and augite-andesites and their tuffs and agglomerates.

The smaller volcanic islands are mostly composed of recent andesitic lavas and pitchstones⁶⁴ with their fragmental rocks, but in some cases the older igneous rocks also occur.

The island of **Savo** possesses a distinct crater-ring, which was in eruption in 1847. The base of the crater is at a height of 1000 ft. Fumaroles and boiling springs occur; the rocks are hornblende-pyroxene andesites⁴⁵. The island of **Vella Lavella** is likewise active with fumaroles and solfataras.

Other islands of the group are partly composed of calcareous and partly of volcanic or old igneous rocks. Thus, in **Florida** or **Ngela Island** foraminiferal and coral-limestones occur up to a height of 900 ft., but older granulites compose most of it and other metamorphic rocks, altered gabbro, and serpentines and later andesitic tuffs⁶⁴ are found in some places.

The small island of **Tulagi** is stated⁴⁵ to have a fine-grained, buff-coloured clay containing sponge-spicules and radiolarian tests.

The island of **Piedu** shows some interesting altered compact cherty limestones, but it is mainly composed of andesites.

In **Simbi (Narovo)** or **Eddystone Island** there is a crater in the solfataric stage with many fumaroles and small well-preserved craters and cones. The lavas are pyroxene-andesites.

There is also a large number of the islands which are composed mainly or entirely of calcareous rocks, and these include (a) the innumerable islets on the coral reefs at the present sea-level; (b) those less than 100 ft. in height, such as the **Three Sisters** and **Stirling Island** entirely composed of coral-limestones; and (c) those

of larger size and height, such as **Ugi** and **Choiseul**, consist of partially consolidated foraminiferal muds or oozes. But some show a nucleus of volcanic rocks.

The sedimentary rocks which occur in these and other of the Solomon Islands are (1) coral muds and sands formed of detritus from coral reefs and of molluscan fragments ; these are usually friable and chalky in appearance ; (2) volcanic muds, partially consolidated and bluish-grey or chocolate in colour, with only 5 per cent, to 20 per cent, of carbonate of lime, probably formed in water 300-1900 fathoms deep ; (3) pteropod oozes, of a greenish-grey colour, deposited at any depth from 100 to 600 fathoms ; (4) foraminiferal oozes composed of both pelagic and benthic forms, and often hardened into limestones ; (5) deep-sea clays of a yellowish-brown colour, with only about 20 per cent, carbonate of lime, the rest being composed of fine fragments of minerals and argillaceous material ; these clays are believed to have been laid down in water of not less than 2000 fathoms. In **Santa Anna**, which is an upraised atoll, this deep-sea deposit is upraised, resting on the volcanic nucleus and covered by thick coral-limestone ; (6) massive coral-reef limestones, forming solid rocks or reefs of recent formation ; these occur on most of the islands.

One peculiar limestone composed of the shells of *Rhynchonella* and of many gastropods, lamellibranchs, and some deep-sea corals, is found in one of the **Shortland Islands** at the south end of Bougainville, which also possesses a core of quartz-diorites and epidotised tuffs overlain by foraminiferal and pteropod oozes and recent calcareous rocks.

In some cases, as in the Island of **Ugi**, the calcareous beds are disturbed and regularly folded⁴⁵, while in **Treasury Island** the soft foraminiferal deposits, of which the mass of the island is composed, are regularly stratified, and dip generally at low angles away from the elevated interior ; they must have been deposited in a sea of perhaps 1800 fathoms, and therefore appear to indicate, when the height of the island is taken into account, an uplift of 12,000 ft., as Guppy maintained.

Rennell, or **Mungava Island**⁴⁵, 100 miles south of Guadalcanal, is regarded as the best existing example of an elevated atoll and has coral cliffs 500 ft. high, with a lake of fresh water 10 miles long at its eastern end, filling the former lagoon.

The whole group of islands is undoubtedly of continental origin, but since the break-up and erosion of the land-mass of which they formed a part, the group must have been subject to great movements of depression and elevation, while for a long period it has been marked by volcanic activity which continues to the present day.

SANTA CRUZ ISLANDS

The **Santa Cruz**⁴⁵ (or **Queen Charlotte**) Islands, lying about 200 miles east of the Solomons, and 100 miles north of the New Hebrides, are separated by an ocean of over 2000 fathoms in depth, and are apparently of volcanic origin. Porphyritic olivine-basalt has been recorded from one of the islands.

THE TONGA OR FRIENDLY ISLANDS
(PROTECTORATE)

This group^{2 17 24}, lying about 400 miles south-east of Fiji between 18° and 22° S. lat. and 174° to 176° W. long., has its axis directed N.N.E., and is situated on a ridge running S.S.W. through the Kermadec Islands to the East Cape of New Zealand. As above mentioned, Suess³ termed this line the ^kThird Australian arc,' being one of the arcs diverging from the north end of New Zealand, and Marshall^{4 38} also regards this Tonga-Kermadec-New Zealand line as an important structural feature in the south-west Pacific. 'The soundings along this ridge are shallow. The summits that project above the ocean along its crest are nearly all volcanic on the west side of its axis, but of raised limestone on the east. The whole line is bounded by a profound ocean-deep on the east side. Relatively shallow water connects it with Fiji and the New Hebrides, and in all the islands the volcanic rocks of Cainozoic age are mainly andesites, as in the North Island of New Zealand. Everywhere to the east of this curved line the unbroken depths of the Pacific extend to the American coast, except for the few isolated island-peaks which here and there rise above the ocean surface.' According to Phillips²⁴, this structural line is marked by volcanic activity, as is usual along the edge of a foundered area, and it is probably prolonged southwards to Macquarie Island (159° E.), and even to Mounts Erebus and Terror in the Antarctic.

The Tonga Ridge itself, which is nearly 200 miles in length, with an average width of over 20 miles, is broken up into four plateaus separated by deep valleys, and forms an enormous elevated mass of Tertiary limestone. Agassiz¹⁷ held that Recent corals played no part in its formation or in that of the present masses of land, but this may be questioned.

In the Tonga Islands, according to Lister², there may be distinguished three lines or linear groups of islands; the eastern line is almost entirely of raised coral; the middle one (less regular) is mainly of volcanic tuffs; the western one is volcanic, and includes only small islands carrying several active or dormant volcanoes, and this line is parallel to the trend of the main Tongan Ridge.

Of the limestone islands the northern ones around Vavau show three distinct terraces at heights of about 140 ft., 300 ft., and 500 ft. above sea-level, indicating pauses in its elevation.

Near the southern end of the group the large island of **Tongatabu**⁷¹, some 22 miles in length, is formed of coral-limestone throughout, and may be an unequally upraised atoll, the interior of which is now occupied by a shallow lagoon. The massive Umestone of this island contains a considerable molluscan fauna of living species⁷¹, and is referred to late Pleistocene.

The island of **Eua**^{42 72} appears to have an ancient plutonic basis. On a foundation of rhyolite flows rest andesitic fragmental deposits consisting of beds of ashes sometimes horizontal, but sometimes much disturbed, and containing some organic remains (foraminifera, etc.). Dykes of intrusive augite- and hypersthene-andesites penetrate these tuffs, but do not pierce the thick overlying limestones. The latter show six well-marked terraces up to the summit of the island, over 1000 ft. above sea-level. The oldest limestone is of Eocene age. The limestones are composed of the fragmentary remains of mollusca, echinoderms, polyzoa, and calcareous algae, together with a large number of foraminifera. A species of the cephalopod *Aturia*, comparable with *A. aturi*, has been found⁴⁸ in horizontally bedded volcanic tuff overlying the Eocene limestone, indicating a Miocene age for the bed.

About 50 miles north of the Tongan capital there is a small island, known as **Falcon Island**^{81 82} or Foonuafo'o, which, from time to time, appears above the surface, for it is formed only of scoriae thrown up by intermittent submarine volcanic eruptions. In 1928 it formed an island 2 miles long, 365 ft. in height, with a shallow crater⁸². But its existence in all cases is short-lived, and it is soon washed away, leaving only a shoal without a sign of volcanic activity. No lava-flow has ever been observed, and only scoriae appear to form it.

Several islands in the **Hapai Group** are formed of layers of submarine volcanic ash and calcareous sand. Some nodules of manganese occur in these beds.

The volcanic islands include **Kao**, which reaches a height of over 3000 ft., and some are in a state of intermittent activity. The rocks consist of augite-andesites and include lavas and ashes.

The Tonga line of volcanoes which, as stated, is parallel to the axis of the Tonga Plateau, meets the Samoan line to the north at right-angles at Savaii, which is the largest volcano of either group.

Economic Geology.—Large deposits of sulphur are stated to occur on Late Island and Fonualei Island²⁴.

KERMADEC ISLANDS

These islands^{2 5 6 35 65}, belonging to New Zealand, form a small but widespread linear group of four main islands of volcanic origin situated 30° S. lat. 178° W. long., on the tectonic⁶⁷ line running north from New Zealand to the Samoan Islands, and there are still some active craters amongst them. There is a large crater on **Sunday Island**, and solfataric action is still apparent; this island measures about 20 miles in circumference and rises to a height of over 1700 ft. **Macaulay Island**, **Brind Island** and the **Curtis Islands**, are the other principal members of the group. The larger of the Curtis Islands has a small crater, also still showing solfataric activity. The lavas of the Kermadec Islands are mostly augite-andesites⁶⁶, but there are also a few basalts, with much tuff and scoriae. The nature of the basement upon which the volcanoes were built seems indicated by boulders of bornblende-granite which occur on Sunday Island in the tuffs.

Deposits of sulphur are found in this group of islands as in the Tonga Group.

THE FIJI ISLANDS

The **Fiji Islands**^{8 10 11 13 14 17} 30 40 44 86 including the **Yasawa** and **Lau Groups**^{13 36 84} which lie respectively to the west and east, are situated between the parallels of 16° and 19° S. lat. and 177° E. long. and 178° W. long. They number about 250, but two of the islands, Viti Levu and Vanua Levu, are much larger than the rest, and show a more complex geological structure. Viti Levu has a length of about 96 miles and a width of 63 miles, with an area of over 4000 sq. miles, while Vanua Levu is about 120 miles in length, with a width of about 30 miles. Ladd⁴⁴ believes that the presence of plutonic and metamorphic rocks on Viti Levu and on many of the islands in the south-west part of the Pacific point to the former existence of a Melanesian continent which joined Asia to Australia and extended south-eastward into the present Pacific basin. The breaking up of this continent by extensive faulting followed a period of compression and folding and may have lasted over a long period of geological time, but chiefly took place during the Miocene, though it may have started earlier. A connection between the linear arrangement of volcanic vents and the lines of fault is suggested, such as is seen in the Northern Island of New Zealand, the Kermadec Islands, and Tonga Islands, and in the trend of the mountain backbone of Viti Levu⁴⁴. Woolnough¹⁴ and Speight⁶⁶ have also believed in the continental origin of Fiji. The erosion of these continental fragments formed the antecedent platforms⁸⁵ on which many of the islands and atolls in the Fijian Archipelago were built up. Their

history and relations to the rest of the islands in the South Pacific have been traced by Davis^{60 61 68} and Ladd⁴⁴.

Volcanic rocks enter principally into the composition of the whole group, but many of the islands consist partly of coral or foraminiferal limestones of more than one age, and in the two larger islands there are central cores¹⁴ of plutonic and ancient sedimentary rocks and more than one series of later marine strata which are partly involved in the folds and other crustal movements which have affected the area. It is rare to find well-preserved volcanic cones or craters in the islands, owing to prolonged erosion since the last eruptions, but on Taviuni there are four large cones and many small ones rising along part of the axis of this island, and recent lava-flows cover some of the reefs. It is considered by Foye³⁰ that there have been four periods of volcanic activity in Fiji, of which the first was characterised by rhyolites, and was followed without a perceptible interval of erosion by andesites. A long period of erosion then occurred and was succeeded by subsidence and by the deposition of marine (Miocene) sediments, as seen on Viti Levu (see below). A second outburst of andesitic eruptivity accompanied the uplift which marked the next stage in the history of the group. Then occurred another period marked by erosion, subsidence, and the deposition of sediments which are mostly volcanic tuffs ('soapstones'). A re-elevation followed, and a series of basaltic eruptions took place and continued till recent times. According to Guppy⁷, at the west end of Vanua Levu there are basic tuffs succeeded by acid tuffs in this latest volcanic series of submarine origin.

We do not possess at present sufficient evidence to fix the age of all these events, and the testimony of the fossils is somewhat ambiguous. But the folded series of sedimentary rocks in the interior of Viti Levu (see description below), which have not been discovered in Vanua Levu, resembles the folded series of the New Hebrides which Mawson³⁹ believes to be of Miocene age, and there has been found in the elevated limestones of Mango in the Lau Group^{13 31} (and probably of Namuka) a species of foraminifera, *Orbitoides sumatrensis*, identical with a Miocene form occurring on Christmas Island in the Indian Ocean as well as in Sumatra.

The sedimentary beds forming the Coastal Plain Series in Viti Levu, on the other hand, have low dips and are considered by Foye³⁰ to be probably post-Tertiary in age, though Dall¹² regarded the fossil mollusca in them to be possibly either Miocene or Pliocene, and Woolnough has stated that the elevated reef near Suva contains an assemblage of fossils apparently not newer than the Pliocene. Brady¹⁰, however, had previously declared that the marls associated with the coral-limestones of Suva were certainly post-Tertiary in age, for of the ninety-two species of foraminifera identified in them,

eighty-seven are still living in the Pacific. These early collections of fossils do not appear to have been made with sufficient attention to stratigraphical horizons, and consequently their evidence as to the age of the beds in some cases seems to be contradictory. The recent work by Brock⁴³, and especially by Matley and Davies⁴⁰, however, enables the age of the beds to be accurately determined, the fossils also being now correctly identified. It is possible that the formation of the beds comprised in the Coastal Plain Series covers a considerable period of geological time.

The elevated marine volcanic rocks of Vanua Levu, and the upraised limestones of the Yasawa and Lau Islands, which have suffered no folding in the process, are held by Foye to be Pleistocene or Recent and of the same general age as the Coastal Plain Series^{30 31} (see below). The induration and metamorphism of the limestones appear to be due to processes still at work, but the extent of the changes seems in some measure an indication of the age of the rock.

In **Viti Levu**^{15 40 43 44} the south-eastern and much of the eastern side of the island is occupied by a low delta-flat which merges into a coastal plain, extending 5-10 miles inland to meet an uplifted mass of marls representing a former delta-plain. The latter slopes upwards from its edge till it rests unconformably against the interior volcanic hills at heights of 600-700 ft. The coast-line of the greater part of the circumference of the island is formed by similar volcanic hills which rise in the interior to a height of over 4500 ft. Mountain ranges and linear ridges of volcanic peaks separate the coastal plains from the interior plateaus. The plateau of Tholo West in the western part of the island has its northern scarp rising 2000 ft. above the coastal plain and forms the most conspicuous topographic feature of the island⁴⁴.

The formations present in the island consist of a pre-Tertiary (? Mesozoic) series, constituting the core of the island, and of a Tertiary series, partly igneous, which occupies most of the surface of the island. In the south-western part of Viti Levu, and in various parts of the interior, the old basement of plutonic and ancient sedimentary rocks is exposed, amongst which granite, diorite, gabbro, diabase, foyaite, quartz-porphyry, eurite, amphibolite, etc., have been described, but some are only known as pebbles in the river-gravels. Quartz-mica-schist, quartzite, red sandstone, arkoses, schalstein, slates, and granular limestone seem to belong to this older series into which the igneous rocks were intruded. The presence of these old sedimentary rocks is of much interest, for it indicates a continental origin of the islands. The granites are intensely jointed and show many signs of great earth-movements. Brock⁴³, in his sketch of the geology of the island, recognises a basement formation of metamorphic rocks¹⁴ (*Wanimala*

Formation) into which the granites, diorites, and gabbros (*Tholo Plutonics*) were intruded, and they accompanied or immediately preceded great earth-movements which he terms the *Tholo Revolution*. A period of erosion followed before the so-called *Singatoka Volcanics*, consisting of andesites and rhyolites, were poured out. Unconformably resting on them is the *Viti Formation* of Middle Tertiary (Miocene) age, consisting of conglomerates, sandstones, marls (soapstones), and limestones from which the fossils comprising foraminifera belonging to *Lepidocyclina*, *Miogypsina*, and other genera⁴⁴ have been collected, as well as a few corals; these point to a Lower Miocene age^{40 58 62}.

Another series of earth-movements of a mountain-building nature resulting in considerable folding of the beds has been termed by Brock the *Viti Revolution*; it succeeded the *Viti Formation*, but preceded the outpouring of certain other lavas (andesites and basalts) accompanied by tuffs and agglomerates, and named by Brock the *Ba Volcanics*. After a period of denudation there followed the deposition of the so-called *Suva Formation*, consisting of sandstones, marls, foraminiferal- and coral-limestones, and soapstones, which Yabe⁶² refers to the Miocene but Brock included in his *Coastal Plain Series* of Pliocene or Pleistocene age. The *Suva Formation* is, however, put entirely in the Neogene by Ladd⁴⁴, together with the *Singatoka Volcanics* and the *Viti Formation*, and the term *Suva Formation* is used also to include the *Ba Volcanics*. The *Suva Formation*, as thus understood by Ladd, covers most of the island. There is a younger as well as an older fauna in the *Suva Formation* as thus understood, but there is a difference of opinion as to the age of the younger fauna, which seems to be Pliocene in its foraminiferal and molluscan character, while the older fauna is Miocene; there seems to be no sharp division between the Miocene and Pliocene in the South Pacific. The foraminifera of the *Suva Formation* have been described by Cushman and Whipple⁴⁴ and Sherlock⁷². The echinoidea include the genera *Cystechinus* and *Chelonechinus*⁷¹, which occur also in the radiolarian marls of Barbados and have been described by Hawkins⁴⁴; the corals have been studied by Hoffmeister⁴⁴, the Crustacea by Rathbun⁴⁴, and the other fossils by Mansfield⁵⁸ and Ladd⁴⁴ amongst other authors. The petrography of the rocks has been studied by Pegau⁴⁴ and others^{9 14}. Thick masses of the limestone of the *Viti Formation* form precipitous hills or cap many of the interior heights and in places are tunnelled with caverns. In some cases the limestone is marmorised by the intense folding it has undergone.

The beds of the *Coastal Plain Series*, which reach a thickness of 100-300 ft., have only low dips, being thus in contrast to the rocks of the highly-folded older series; they also contain boulders of the older

limestones. As examples we may point to the marls along the south-eastern coast of the island and the coral-limestones interbedded with them about Suva Harbour, which yield corals of Pleistocene or Recent age, as well as the post-Tertiary foraminifera described by Brady and the teeth of *Car char odon*.

The marls, which are commonly called 'soapstones'¹⁰, are fine light grey or white friable detrital volcanic muds in places at least 300 ft. thick¹³ and crowded with foraminifera³¹. It is believed that they indicate a depth of 150-200 fathoms. The soapstones¹⁰, which are fine volcanic tuffs and foraminiferal marls of a special type, contain in places pteropods and small mollusca and the echinoid *Cystechinus*. But they are not all of the same age. Some layers of a dark purplish colour, resembling a fine sandstone, contain as much as 60 per cent, silica, but the others average about 50 per cent. As above stated, these marine sediments were raised and eroded before the final basaltic outburst of volcanic activity took place, during which basaltic dykes were injected into them. According to Ladd⁴⁴ no true extinct craters occur on Viti Levu, and there are no active volcanoes, but some of the lava-flows and igneous intrusions may be of recent date. The earth-movements of recent date are of a simple elevatory nature, and have raised coral-reefs and coastal deposits to an extent which is not equal over the whole island. These reefs contain a rich fauna³¹. There are some high-level fresh-water beds of feldspathic sandstones, etc., at a height of about 1100 ft. near Nasogo, of probably Pleistocene age, which contain plant-remains⁴⁰. At the south-west end of the island there are numerous perfect volcanic cones with smaller cones on their slopes. On the high plateau of the interior, which nearly reaches the north coast, the level-bedded tuffs (soapstones) are stated by Woolnough¹⁵ to be associated with the basic (limburgite) volcanic series, and to reach an elevation of over 4000 ft. Petrologically the andesitic lavas of Viti Levu are of various types^{9 14}; but the basalts are mainly of the olivine variety and include limburgites. Thermal springs are found in six localities on Viti Levu, and some seem to arise along fault-planes.

The **Yasawa Group** of islands show that andesitic eruptions continued during the accumulation of some of the limestones of the coastal plain period. These limestones, which in places rest on the andesites of the third volcanic period, have been unheaved and eroded, and have been more or less covered by the agglomerates, etc., of the last or basaltic period. Recent movements have depressed these islands.

In **Vanua Levu**^{7 30} the majority of the rocks of which it is composed are stated by Foye to consist of andesitic ash and agglomerate,

but a series of rhyolitic ash-deposits occurs along the north-eastern coast, and the western part of the island is characterised by basalts of later date. The rocks of the eastern end of the island seem never to have been submerged, but the andesites of the central part of the island are of submarine origin, and once formed a wide submarine platform which was subsequently elevated 3000-4000 ft., and has since then suffered prolonged erosion.

The old plutonic basement rocks which occur on Viti Levu are known also from several localities in Vanua Levu situated along a mountainous ridge running in a N.E.-S.W. direction, and include gabbros and norites. The oldest volcanic rocks are the rhyolites and andesites in the Lambasa district and include lavas, ashes, and agglomerates. The rhyolites are characteristic of the northern coast east of Lambasa. A great subsidence took place after their eruption, and was accompanied by the deposition of marine tuffs and agglomerates of the second andesitic period, according to Foye. These marine tuffs apparently correspond to the volcanic muds, foraminiferal clays, and submarine palagonite tuffs described by Guppy⁷; they are mainly horizontal and occur in the elevated interior of the island up to heights of 2500-2700 ft., but are often concealed by later tuffs and agglomerates. Similar rocks occur in the New Hebrides (*q.v.*). At the east end of the island the separation of the above-mentioned first and second andesitic periods is more distinct than in the Lambasa district. In this latter district, and in Savu Savu Bay, there is evidence of another subsidence after the elevation and erosion of these deposits, and 50-100 ft. of coastal sediments were laid down un conformably on the much-eroded andesites. This set of deposits seems to include some of the pteropod and foraminiferal oozes which have been described by Guppy. After another uplift there was an eruption of basaltic lavas (mostly of the hypersthene type), accompanied by agglomerates in the Savu Savu district, while at the west end of the island (where Mount Seatura shows a well-preserved cone) olivine-basalts were poured out and form the Wainunu tableland, as well as some isolated mountains. On the island of Taviuni off the east of Vanua Levu, the cones and craters from which the basaltic lavas flowed are well preserved, and must be comparatively recent. Petrologically most of the lavas are olivine-basalts. A number of hot springs⁷ of high temperature which in some cases deposit siliceous sinter, are scattered over Vanua Levu and point to dormant or dying volcanic activity.

A partial submergence of later date than any of the volcanic eruptions affected most of the Fijian group, but a gradual movement of elevation is now going on in places.

River-conglomerates of coarse gravel occur in both Viti and

Vanua Levu, and appear to have been formed at more than one period.

According to Guppy the island of Vanua Levu has been formed by the union of a number of smaller volcanic islands during a long period of intermittent emergence. The first stage is considered to be represented by the elevation of the earlier deposits to above 1000 and up to 2700 ft., and is termed the 'pre-Lau' stage; the second uplift did not raise the island more than 1000-1200 ft., and is called the 'Lau Stage.' But, according to Foye, as above mentioned, the history of the island is not so simple.

In the **Lau Group**^{13 36 84} of about 100 islands, bounding the Koro Sea on the east, the oldest rocks are andesites of the second period of andesitic activity. After the erosion of these rocks submergence took place during which coral-limestones, the Futuna⁸⁴ limestones of Miocene age (and, according to Andrews³³, soapstones of the Fijian type), were laid down. These limestones are rich in algae and foraminifera⁸⁴, especially species of *Lepidocyclina*, but mollusca, echinoids, and corals also occur in them, and they are correlated with the Suva Formation of Miocene age. Upheaval followed the deposition of the limestones, and the uplifted masses of reef-limestone form now a characteristic feature of the group. Later further eruptions took place by which olivine basalts were poured out over them and agglomerates accumulated, much of which have been removed by subsequent sub-aerial denudation. A later submergence seems to have affected most of the islands, and more limestones of Pliocene age were deposited. After the close of the Tertiary intermittent movements of uplift took place.

Some of the islands in the Lau Group are entirely volcanic, others are composed entirely of limestone. Silicified corals, as in Vanua Levu, derived from the vanished limestone masses and possibly owing their condition to the action of the hot springs, are in places scattered over the andesitic hills. In the **Exploring Group** the limestones seem to have been deposited during the subsidence to a thickness of 400 ft., and the previously eroded land was fringed with reefs.

The whole Fijian Group^{4 14 15 30} seems to have belonged to a continental mass including New Caledonia, the New Hebrides, New Guinea, and perhaps New Zealand, and biological evidence is stated to be completely in accord with this hypothesis. Ladd⁴⁴, as above mentioned, believes that they all formed part of a Melanesian Continent. The whole group seems to have been marked by uplift rather than subsidence in Pleistocene and Recent times, and several lines of beach-erosion are traceable on the cliffs of some of the islands (*e.g.*, Vatu Leile)¹³, but the earth's crust in this region has been most unstable, and the submergence of platforms of

erosion⁸⁵ at various times has produced conditions favourable to the upgrowth of barrier-reefs and atolls which are partly represented by the elevated limestones in the islands. The bulk of these raised reefs is composed of calcareous algae and foraminifera, corals being rare³¹. The modern reefs represent another cycle of events and have been developed on antecedent platforms or benches produced by more than one process^{30 33 41}. The apparently conflicting evidence⁶⁰ for the upheaval and subsidence of different parts of the island group can be explained, according to Davis⁴¹, by his theory of a migrating anticline. For the islands of south-central and south-eastern Fiji can be arranged in four or five north-and-south trending belts which show a similar sequence of phases of movement, but do not agree in the date of their occurrence, the western belts being affected later than the eastern, as Davis' theory would explain. The great barrier reef surrounding Viti Levu and Vanua Levu has been probably built up on the recently submerged lowlands of these islands which have had the lower portions of their river valleys 'drowned'^{22 33}, resulting in the formation of deep coastal indentations.

The island of **Rotuma** (12° 30' S. lat., 117° 1' E. long.) rises from the same great submarine plateau as the Fiji and Tonga groups, and is composed of volcanic rocks (vesicular basalt, olivine-basalt, olivine-dolerite, and volcanic ash), and more than one volcanic crater occurs on its surface¹⁰. There is also a more or less consolidated calcareous sandy deposit containing fragments of corals, mollusca, etc., which is of recent littoral or oolian origin.

Economic Minerals.—A great deposit of manganese occurs on Mango about 100 ft. above high-water mark¹³. Gold is mined on Viti Levu and Vanua Levu in the old basement rocks.

ELLTCE GROUP

The Ellice, Gilbert, and Marshall Islands are members of Dana's 'Polynesian chain,' trending from north-west to south-east. Suess placed them on his 'Second Australian arc,' running from the Caroline Islands to the Fiji Group.

The islands in the Ellice Group, which is situated about 9° S. lat. and 179° E. long., are of coral origin¹⁷ and consist of nine small clusters scattered over 400 miles. The atoll of **Funafuti**^{17 22 24~26} rises from a depth of 3000 fathoms. The boring which was made to test its structure was carried down for 748 ft. in material so slightly cemented that it mostly crumbled to powder; from this depth to **1114** ft., more than four-fifths of the material was solid coral-rock, and the corals were found in the position of growth.

All of the twenty-eight genera of corals recognised in the bores belong to well-known reef-building forms, and most of them and of the foraminifera live on the present reef, so that there was no evidence of the presence of a Tertiary coral-formation; the character and contents of the rock, however, point to subsidence. In the lower part of the bore the calcareous rock had become a dolomite.

GILBERT GROUP

These islands, sixteen in number, which are situated on the Equator (165° E. long.), constitute a series of isolated peaks and ridges, and are of coral-limestone formation¹⁷; some are recent atolls, but there is a limestone in one island which is said to be identical with that on Eua of the Tonga Group (see p. 693), and on Ocean Island (Paanopa)^{17 38 52 65} it has been more or less phosphatised by deposits of guano¹⁸, in some places 80 ft. thick. Neither Ocean nor Pleasant islands are atolls, but are elevated masses of coralliferous limestone. Since the coral formation has been raised to a height of over 250 ft. in some of the islands (270 ft. in Ocean Island), it is evident that a considerable uplift must have taken place, and there is also proof of much subsequent denudation^{17 18}.

Ocean Island³² appears to consist of three or more slightly tilted platforms rising in successive steps with nearly vertical cliffs facing the sea and marking levels of marine erosion and pauses in the uplift. These were formed prior to the accumulation of the phosphatic deposits⁶⁵ which cap almost the whole of the island and are usually less than 50 ft. thick. The phosphate may be incoherent or coherent, the latter forming the so-called phosphate-rock. The coral directly below the phosphate is almost wholly dolomitised. The removal of the phosphate rock and the subsequent weathering of the coral-limestone platform has led to the production of a jagged mass of closely packed pinnacles of rock often 30-50 ft. high⁶⁵.

Nauru, or Pleasant Island, sometimes placed in the Marshall Group, is composed of raised coral-limestone and has an elevated rim suggesting an old uplifted atoll. The island reaches a height of 220 ft. and is terraced. The limestone is said to be identical with that in certain members of the Tonga Group¹⁷. Phosphatic deposits of importance^{65 72} occur on it. There is a remarkable 'swallow-hole'¹⁵² on the central tableland, and caves of considerable size exist in various places.

COOK ISLANDS OR HERVEY GROUP⁵¹¹

This group of islands, belonging to New Zealand, is situated in 20° S. lat. and 160° W. long., and lying on one member of Dana's

'Polynesian chain,' which strikes in a general N.W.-S.E. direction; it is partly of volcanic and partly of coral-limestone formation, and shows evidence of considerable oscillation and of a tilting movement which was greatest in the south and east. The coral-limestones are said to indicate upheaval to an extent of 20-200 ft. **Rarotonga**^{19 51 75}, which rises to a height of nearly 3000 ft., is composed of volcanic rocks of several types, such as a coarse porphyritic basalt with olivine, like that in the Society Islands, ankaramite, a nephelinite or nepheline-phonolite of later date, and other types of phonolite. Much volcanic breccia also occurs. The basalts include lavas and dykes, as well as tuffs, and the phonolitic rocks are represented by lavas and tuffs⁷⁵. **Atiu Island** consists almost entirely of coral reefs which apparently began to be formed in Pliocene times. There is also some basalt on the island⁷⁵. There is no evidence on Rarotonga of elevation as there is on the neighbouring island of **Mangaia**, which consists of a central mass of basalt, though probably the oldest rocks are represented by blocks of norite. With the basalt-flows are tuffs; then come Eocene limestones containing foraminifera, then more bedded tuffs with Miocene or Pliocene foraminifera, and finally younger limestones. The growth of coral reefs seems to have been continuous from the Middle Tertiary to the present day, and they encircle the central volcanic core of basalt⁷⁷. On **Aitutaki** nepheline-basalt and dolerite are found^{51 75}. **Hervey Island** and **Palmerston Island** are atolls, and most others in the group have barrier reefs.

NIUE ISLAND

The small island of Niue, which is situated between the Cook and Tonga groups, and is apparently composed entirely of limestone, is interesting because it shows four terraces of elevation and its centre is rather lower than the rim. The age of the limestone has not been determined.

SMALLER ISLANDS NEAR THE EQUATOR

The islands of Maiden, Starbuck, Caroline, Christmas, Fanning, Palmyra, Suwarow, Tokelau, and the Phoenix Group, south of the Hawaiian Islands, are all composed of coral-limestone, and many of them are atolls.

The Phoenix Group includes Enderby Island, jointly owned by Britain and the United States.

PITCAIRN ISLAND

This small isolated island, situated in 25° S. lat., 130° W. long., is said to be composed of basaltic rocks, but a hypersthene-andesite

has also been obtained from it^{4 51 85}, and Lacroix⁵¹ mentions andesites and trachytic tuffs. M. Levy described olivine-basalts, tachylites, and andesites⁸⁵.

NORFOLK ISLAND

The greater part of Norfolk Island, which is situated lat. 28° S., long. 168° E., is composed of basalt, but recent coral rock also enters largely into its structure^{4 28 29}.

LORD HOWE ISLAND

Lord Howe Island²⁰ is situated about 400 miles from the Australian coast in lat, 31° 30' S. and long. 159° E. Two-thirds of this island are composed of volcanic rocks, of which there is an older series of diabasic rocks of pre-Tertiary or perhaps Palaeozoic age, and a younger series, comprising olivine-basalts, but mainly consisting of agglomerates of a basaltic nature, which lie horizontally and are traversed by dykes of varying width weathering out as walls on the surface. The typical basalts are Tertiary or post-Tertiary, but there are no traces of recent lava-streams or craters. On this volcanic series rests a bed of red clay succeeded by coral-sand rock, probably of aeolian origin, divided into two series which are separated by an unconformity and have a maximum thickness of 250 ft. These sands contain shells of Recent species and bones of the extinct chelonian *Meiolania*, which also occurs in the Pleistocene of Queensland.

MACQUARIE ISLAND⁸³

This island, which lies between the Tasman Sea and Antarctica on the summit of a submarine ridge running north and south for about 150 miles, is about 21 miles long by 1|-3 miles wide, and consists of a basement of basaltic lavas invaded by gabbroic masses and ultramafic dykes; the whole series was much folded and eroded before the deposition of a later series of basalts and pyroclastics, largely of submarine origin and including masses of *Globigerina* ooze. Glaciation on a large scale has since taken place, with the formation of till composed chiefly of the basement rocks, but also containing blocks of sandstone and dunite.

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SECTION V.—SAMOAN ISLANDS

The Samoan Islands^{4 15} form one of the groups in the Pacific which have a trend from W.N.W. to E.S.E., and lie on one of the linear series composing Dana's 'Polynesian chain,' but on Suess' 'Third Australian arc' Daly¹¹ considered that they nearly form a prolongation of the double chain of volcanic islands which includes the Cook and Tubuai Groups. Stearns¹⁵ has recently given a full description of the whole group, which comprises some American and some British islands. The Samoan Islands are placed almost at right-angles to the line running up north from New Zealand through the Kermadec and Tonga Islands, and it is believed that they lie along a tectonic line of weakness or a volcanic fissure, for volcanic action is conspicuous¹⁰. There is evidence that there has been a progressive shifting of the centre of volcanic activity from east to west in this group, the eastern islands having suffered much more erosion and sub-aerial weathering than the western, where the craters and cones are much fresher and more perfect and the lavas much less weathered^{8 9}. The British islands (Mandate of New Zealand) comprise Savaii, Apolima¹², Manono, and Upolu^{15 16}, and together constitute Western Samoa^{9 14}. American Samoa includes the large island of Tutuila and several smaller islands, the geology of which has been described by Daly¹¹ and Stearns¹⁵, with detailed penological descriptions of the volcanic rocks¹⁶. Apart from the igneous rocks only beach deposits and coral reefs¹³ of recent date have been recognised in the group.

The two largest islands in the British group are **Savaii** and **Upolu**. Both are composed of volcanic rocks¹⁴.

Savaii, which is the westernmost and measures about 48 miles in length by 25 in breadth, has a well-marked central axial chain of mountains rising to heights of over 5000 ft. and marked by a series of the most important volcanoes in the island. The disposition of the craters and summits seems to be dominated by a longitudinal fissure which is continued to east-south-east by Apolima, Manono, and Upolu⁹. Along this line are ranged the so-called 'prehistoric volcanoes,' but subsidiary lines branch off to other groups of vents. The older volcanic ground is more weathered, overgrown, and dissected by streams. Stearns¹⁵ describes the whole group of Samoan Islands as composed of four great volcanic piles arranged in echelon along two sets of fractures, one running N. 75° E., and the other N. 75° W. The eruptions were largely fissure-eruptions, but the latest lava-flows are connected with tuff-cones. The well-preserved cones and craters and freshly erupted lavas in

many cases are evidence of their recent origin, and volcanic eruptions have occurred in the island within quite recent years⁷. The principal type of lava is olivine-basalt^{2 3 10}, but limburgite, trachydolerite, phonolites, and nepheline-basalt also occur in some of the islands¹⁰. The basaltic lava-flows have usually gentle slopes (from 5°-10°), and often show columnar structure. Fine threads of glassy lava are found around the most recently active vent, similar to the so-called 'Pele's Hair' in Hawaii. The general profile of the island is that of a low dome of basalt, for it is chiefly composed of flows of this lava, ashes and scoriae having played only a very subordinate part in its formation.

The elongated island of **Upolu**, lying east of Savaii, has likewise a median chain of volcanic heights along its whole length; many of the lavas and eruptive cones are recent, but the deeper and more extensive soils, the stronger denudation, the wide flat foreland and thick coral- and shell-sand on the coast suggest that the island has had a longer history than Savaii. According to Stearns¹⁵ Upolu is a deeply-eroded mass of Pliocene lavas, consisting of various types of porphyries, basalts, and andesites. The Pleistocene and Recent lavas are olivine-basalts^{10 14 15}, which partly cover the older series of lavas. The island has suffered gradual subsidences and a drowned barrier reef surrounds the older volcanic foundation. The petrography of the volcanic rocks on Savaii, and especially on Upolu as well as on the American islands, has been recently described by Macdonald¹⁶ and Bartrum¹⁴.

Upolu has furnished lavas of the trachydolerite and nepheline-basanite types, so that the alkaline lavas are here represented, as is the case in the island of Tutuila^{11 15} of the same group, and in many other Pacific islands¹⁰.

Near Apia there are considerable deposits of calcareous tufa deposited by springs.

The island of **Apolima**¹², which shows a good example of a breached crater invaded by the sea so as to form a sub-circular inlet, is composed of volcanic tuffs.

No evidence of a continental basis has been discovered in the Samoan islands, as in Fiji, but it is possible that it is buried under the thick volcanic rocks of comparatively recent origin.

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EXPLANATION

- H.B. Himalayan-Burmese Arc
 I. First Australian Arc (Suess) } Tertiary.
 Ia. Parallel Branch of I.
 II. Second Australian Arc (Suess) } ? Tertiary.
 III. Third Australian Arc (Suess)
 P. Pre-Tertiary lines of folding in Australia (mostly Palaeozoic).
 X. Coastal fault-lines in Australia (late Tertiary).

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A. Australia.	F. Fiji Is.	N.Z. New Zealand.
An. Antipodes Is.	G. Gilbert Is.	O. Ocean Is.
An. Auckland Is.	J. Java.	Pe. Pelew Is.
B. Borneo.	Ke. Kermadec Is.	Ph. Phoenix Is.
B.A. Bismarck Archipelago.	Kg. Keeling Is.	Pl. Philippine Is.
Bt. Bounty Is.	La. Ladrões Is.	Sa. Samoa Is.
Ca. Caroline Is.	L.H. Lord Howe's Is.	Sc. Santa Cruz Is.
Ch. Chatham Is.	Lo. Louisiade Is.	Si. Singapore.
Chr. Christmas Is.	Ly. Loyalty Is.	Sn. Snares Is.
Ce. Celebes.	M. Macquarie Is.	So. Solomon Is.
Cer. Ceram.	Ma. Marshall Is.	St. Stewart Is.
Cl. Campbell Is.	N. Norfolk Is.	Su. Sumatra.
Co. Cook Is.	Na. Nauru Is.	T. Tasmania.
Em. Emerald Is.	N.C. New Caledonia.	Ti. Timor.
E. Ellice Is.	N.G. New Guinea.	To. Tonga Is.
	N.H. New Hebrides.	U. Union Is.

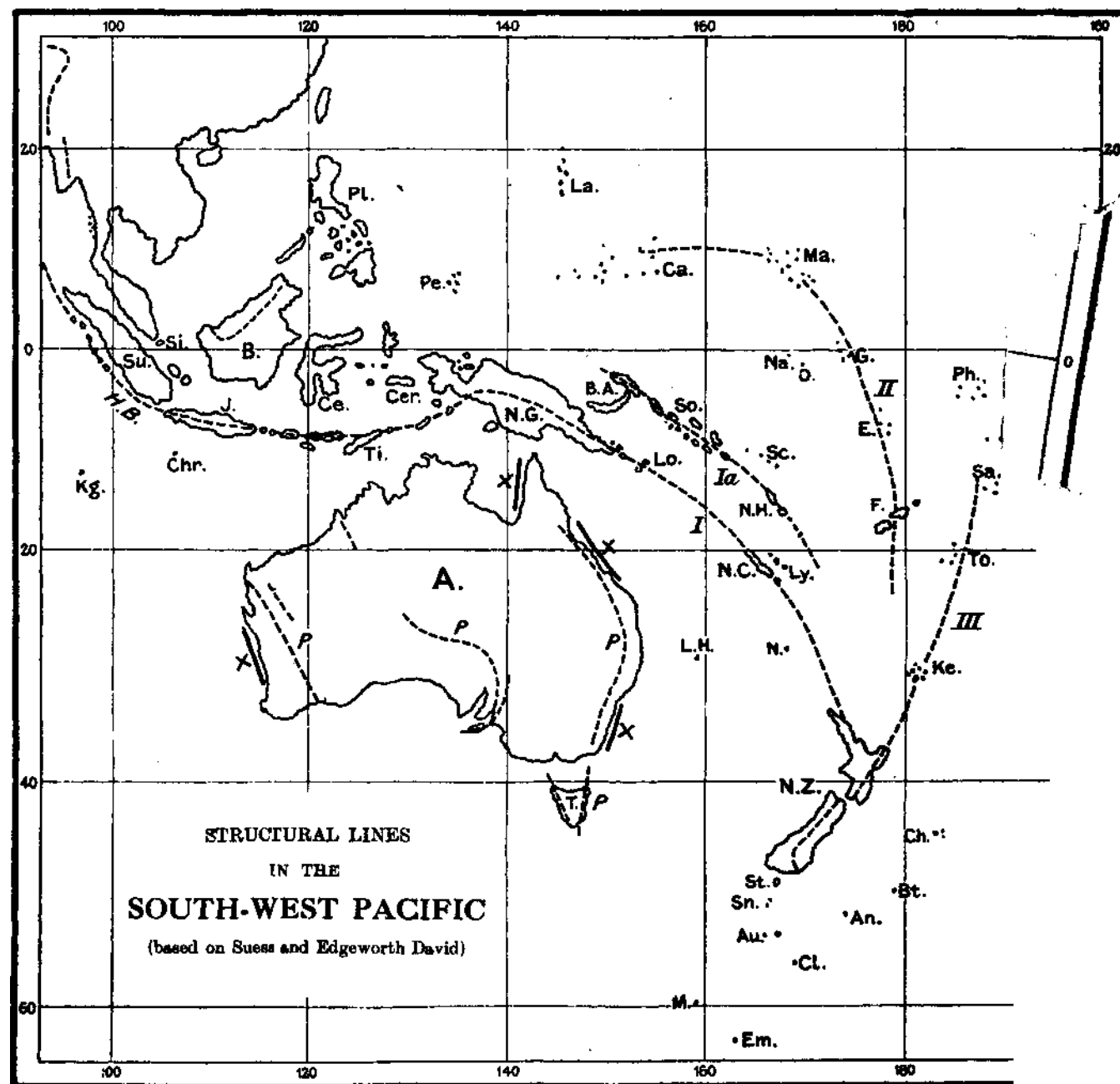


FIG. 20

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SECTION VI.—NEW HEBRIDES GROUP¹⁴

(Condominium with France.)

According to Suess this group of islands, which is spread over an area of 5700 sq. miles, lies on his 'First Australian Arc,' together with the Solomons, and has a general trend N.N.W. The largest of them is **Espiritu Santo**, with an area of 1500 sq. miles, and a high range of mountains rising in Mount Levini to over 6100 ft. in height⁵. On this island there is an earlier volcanic series passing up into Miocene (*Lepidocyclus-Lithothamnion*) limestones which are highly tilted, folded, and faulted. These are succeeded by a later volcanic series of andesitic lavas and tuffs.

On the island of **Malekula** the Miocene foraminiferal limestones, which are tilted and dip up to 28°, have been invaded by dykes and sills of andesite. The island of **Efate** has a base of andesitic tuffs and fossiliferous 'soapstone,' which is described as a fine-grained submarine tuff infiltrated by calcium carbonate; these volcanic rocks are succeeded by a thin veneer of coral rock. Coarse agglomerates also occur on the island.

On **Epi** the marine fossiliferous cinder beds form the lowest rocks, and are overlain by solid coralliferous limestone in which the fossils include lamellibranchs and gastropods of Recent species.

All the islands seem to have suffered considerable uplift, and coral limestone has been recorded on Efate at a height of 1500 ft. The limestones are partly of coral, foraminiferal and algal origin. *Halimeda* limestones of supposed early Pliocene age² are considerably developed.

There are several active volcanoes on the islands **Ambryn**⁸, **Tauna**, and **Yasowa**; fumaroles and hot springs are found on some of the islands. There are also many extinct or dormant volcanoes. The volcanic rocks have been described as chiefly andesitic, but De la Rue⁷¹⁰ states that they are mostly basaltic, and on some islands (e.g. Ambryn⁸) they are so. **Gaua** island seems to consist entirely of a volcano holding a large crater and a secondary cone at the side. De la Rue⁷ recognises three periods of vulcanicity: (1) Miocene, (2) Pliocene and Pleistocene, and (3) Recent. On the **Banks Islands** the lavas are basalt-porphyrates, and the islands are almost wholly volcanic. The **Torres Islands**, on the other hand, are apparently entirely composed of coral rock and are cut into several terraces, the highest being at a height of 1230 ft.

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CHAPTER XVI

PALESTINE

General Structure⁷².—The main physical features of the country are the coastal plain, the western highland or plateau with an average altitude of about 2000 ft., the Jordan-Arabah depression in the floor of the Dead Sea sinking to a depth of nearly 2600 ft. below sea-level, and the eastern highland rising to an average height of 3000 ft. in Moab, and to 4000 ft. farther south in Edom. These form longitudinal parallel belts running north to south and are directly due to the main system of meridional folds and faults which have affected the strata. The principal folding movement which apparently took place in Middle Tertiary (Lower Miocene) times^{14 16} resulted in the formation of a low broad elongated asymmetrical dome with its axis approximately running north and south, but with its western limb considerably steeper than its eastern one. A series of secondary anticlines and synclines were at the same time developed. A later uplift of an epeirogenic character accompanied by warping of the surface took place, according to Picard⁴³, in the transition period of the Plio-Pleistocene. The Miocene uplift in the Lebanon, Anti-Lebanon, and Hermon district amounted to 9000-10,000 ft., but southwards in Judaea it decreased to 3000-4000 ft., while farther south in the Negeb it became still less. A network of faults cuts up northern Palestine into irregular blocks⁴⁰. The longitudinal faulting of the country along parallel meridional lines, which is of primary topographical importance. But there is considerable diversity of opinion as to the period when the chief faulting took place. Picard^{40 43 44 46 53 72} holds that these began in Miocene or even Oligocene times, though later movements may have been along the same lines, so that the whole process was only completed in several stages at successive periods. But, according to Blanckenhorn²², the fracturing only took place in Plio-Pleistocene times. The Jordan Rift Valley belongs probably to the same set of dislocations as that which formed the East African rift-valleys; the formation of the latter must have begun at an early date. The longitudinal dislocations resulted not only in the depression of the Jordan-Arabah Valley, stretching from Mount Hermon to the Red Sea, a distance of 375 miles, with a vertical displacement of 5000-6000 ft. in places, but also led to the formation of the edge of the western plateau by dropping down the coastal strip. At the north end of the Jordan

Valley the depression is continued by the narrow sharp syncline holding the Bkaa and valley of the Orontes, which is likewise bordered by parallel faults bending to the N.N.E. or N.E. The margins of the Jordan Valley⁶⁷ are not defined by single faults, but by a series of step-faults, and the floor does not sink down to an equal and uniform extent, some blocks along its course having sunk more than others. The nature of the long Jordan-Arabah valley and the type of earth-movement which has produced it is disputed, Bailey Willis^{38 46 48} holding that it is due to compressional forces uplifting the plateaus on each side, as in the case of the East African valleys, while Picard^{40 43 44 53 72} and others regard it as formed by ordinary faulting dropping down a long segment of the earth's crust.

Transverse lines of crustal deformation and fracture of other dates than these longitudinal faults have exerted considerable influence on the topography. These transverse faults, according to Picard⁵³, are of Lower or Middle Pliocene age, and, in places in conjunction with the earlier faults, they form crescentic lines of dislocation⁵³. Certain of these faults, according to Blanckenhorn, which trend east and west or south-east to north-west, and are of late Miocene or early Pliocene age, have led to the production of the plain of Rame separating Upper and Lower Galilee, and the plain Asochis, while the fault of Esdraelon, extending south-eastward from Carmel, drops down the country to the north to the extent of 1000-2000 ft., and has resulted in the formation of the plain of Esdraelon and valley of Jezreel. The latest phase in the faulting took place in post-Middle Pliocene times, according to Picard^{40 53 72}, and, according to Blanckenhorn²², in the period between Pliocene and Pleistocene. These latest fractures trend N.N.E. to S.S.W., and correspond to the Erythraean lines of east Africa (q.v.). They were accompanied by slipping and drag-movements. A transverse line of flexure between Hebron and Beersheba, but not crossing the Ghor, causes the region to the south, which is known as the Negeb⁸, to be depressed to the extent of nearly 2000 ft. below the Judæan Plateau. Similarly, on the north of the latter the almost horizontal strata of this plateau are disturbed and thrown into low folds in Samaria along east-and-west lines, while east of the Jordan the downward warping of the crust along a similarly directed transverse line sharply marks off the plain of Bashan from the heights of Gilead. The general plateau of Palestine is finally marked off from the mountains of Lebanon and Hermon by another, though less distinctly defined, east-and-west line, for the strata which lie to the north of the transverse lower course of the Litany River and of the same line prolonged eastwards, are thrown into a series of folds involving a greater variety of geological

formations than are found farther south. The orientation of the lines of faulting in this northern region is less regular, and the lines diverge in a somewhat fan-like manner north of Damascus.

The greater part of Palestine is occupied by Cretaceous rocks^{1 2 24 50}, and there are few older rocks anywhere exposed in Palestine at the surface, except in the extreme south in the Wadi el Arabah south of the Dead Sea, where crystalline schists and granite occur, which are probably of Archaean age, as well as some supposed Pre-Cambrian conglomerates and a small patch of fossiliferous Cambrian beds^{2 22 26}. But in Transjordan, at the north-east end of the Dead Sea, Triassic beds are now known to be present^{28 42 50 69}, and Jurassic rocks^{29 30 50} occur at its south-east end (see below). Beyond the northern end of the country in Syria Jurassic beds⁷³ also appear to the west of Damascus, and are considerably developed around Beirut.

The whole coastal region from south of Gaza northwards to Carmel is occupied by a broad belt of Upper Pliocene, Pleistocene, and Recent deposits^{32 76}, and is cut off by a meridional fault from the Cretaceous inland area. North of Carmel^{33 34} a shorter belt of the same character exists between Haifa and Acre.

Eocene rocks form large faulted patches on the right bank of the Jordan, east of Nablus, and form most of Mounts Gilboa, Ebal, and Gerizim, while north of it isolated outcrops of the same beds are found leading on to long narrow exposures which trend in a general N.N.E. or N.E. direction along the Litany River, and along the eastern side of the Anti-Lebanon north of Damascus. An enormous development of young basaltic lavas spreads over the Hauran and over the country to the south of Damascus¹⁴, but these regions are outside Palestine proper. However, these volcanic rocks cross the Jordan Valley north of the Sea of Galilee, and send a broad tongue southwards nearly to Beth Shan and Little Hermon⁶⁵.

DETAILS OF THE STRATIGRAPHY 1-3 22 24

Archaean.—Gneiss, crystalline schists, granite, granodiorite, felsite, etc.^{25 50 72}, are found exposed on the east and west sides of the Wadi el Arabah, south of the Dead Sea, and belong to the same set of rocks as that which composes the greater part of the Peninsula of Sinai.

Pre-Cambrian.—Coarse conglomerates, arkoses, quartzite, tuffs, and beds of felsitic eruptive rocks are found in the same region in the neighbourhood of Mount Hor (Jebel Harun) and Petra on the east side of the Wadi el Arabah. The whole series is pierced by dykes and masses of intrusive porphyritic rocks. The conglomerates consist of well-rounded pebbles of gneiss, granite, quartz-porphry, diorite, etc.²⁵.

Palaeozoic.

Cambrian^{2 22 26}.—At the south end of the Dead Sea in the Wadi el Hessi and Wadi Saramuj, which descend from the eastern highlands, there are red

sandstones, variegated marls, dolomites, and siliceous limestone or calcareous quartzite, which form a series of beds about 1000 ft. thick. The upper beds of quartzite have yielded remains of trilobites (*Paradoxides* and *Ptychoparia*) and other fossils which prove them to be of a Middle Cambrian age. Recently²⁶ *Anomocare*, *Micromitra*, *Siphonotreta*, and *Hyolithes* have also been recorded from the limestones, etc., also on the east side of the Dead Sea. No Cambrian rocks are elsewhere known in Syria or nearer than Persia and the Salt Range and Himalayas. The beds rest unconformably on the Pre-Cambrian, and are completely undisturbed and horizontal. Copper ores have been worked in these rocks in the past, and bands of iron-ore are interbedded.

Carboniferous.—Although no definite Carboniferous fossils have been found as yet in Palestine it is believed that the occurrence of the manganese-ore series in the shape of purple shales, sandstones, etc., at Wadi Meneiaieh^{49 50}, 30 km. north of Akaba, containing pyrolusite, etc., may be of this age, as it is in Sinai. It is probable also that the lower (red) part of the Nubian Sandstone Series from the south end of the Dead Sea to beyond Petra is of Carboniferous age²⁴ as in Sinai, but there is no fossil evidence available.

Mesozoic.

(1) **Triassic**^{28 50 69}.—In the Wadis Hesban and Ayun Musa, near the north-east end of the Dead Sea, a series of fossiliferous Triassic rocks has been recently discovered, both underlain and overlain by the 'Nubian Sandstone Series.' The beds are mostly calcareous, about 100-150 ft. thick, thinning out eastward, and have yielded a fauna of Carnic age, including *Ocenothyris vulgaris*, *Lima lineata*, *Myophoria Icevigata*, *Pecten inaequistriatus*, etc.

(2) **Jurassic.**—A Bajocian-Bathonian^{29 30 50} outcrop of fossiliferous impure yellow limestone has been recently found at the mouth of the Wadi Jabbok near the south-east end of the Dead Sea. The beds are intercalated in the 'Nubian Sandstone Series,' and contain a fauna predominantly of brachiopods³⁰, but including lamellibranchs and gastropods, with the echinoid *Cidaris glaidaria*, a characteristic species of the Kimeridgian in Syria⁷³. The occurrence of higher Jurassic beds is almost restricted to the region of Lebanon and Hermon, where they are the oldest stratigraphical horizons exposed, and are only brought up by the anticlinal folds, or seen in deeply eroded valleys. Only part of the Upper Jurassic is present, comprising the Oxfordian, Corallian, and Lower Kimeridgian, and these formations are represented by limestones or calcareous marls of various types often rich in fossils. The beds are largely developed east of Beirut, and the summit of Hermon is composed of rocks of this age^{18 73}, where Dubertret⁷³ has described a complete series of beds composed of limestones and marls ranging from the Lias, or Bajocian, to the Tithonian.

(3) **Cretaceous**^{1 2 4 17 18 21 22 50 60}.—This system is by far the most important in Palestine, and covers the largest area⁷² in the country. The Lower Cretaceous^{50 72} (*Albian-Aptian*) is chiefly developed in Transjordan on the east side of the Jordan Valley, but small patches occur also in various parts of Palestine as in Wadi Farah. The beds comprise various kinds of limestones and sandstones with volcanic rocks (basalts and tuffs) in places. The fauna includes *Knemiceras syriacum* and many lamellibranchs. Sandstones containing plant-remains lie below the volcanic beds and represent part of the *Nubian Sandstone Series*. In Palestine proper the sandstone in this series is practically unfossiliferous, but is displayed along the east side of the Jordan Valley, at Jabbok, along the whole eastern side of the Dead Sea, and farther south on the Edom Plateau, as at Petra²⁰. The sandstones,

white, yellow, pink, and brown, which are present in this and the Akaba region are only partly of Lower Cretaceous age, and the separation of these from the underlying Carboniferous (?) sandstones and shales containing manganese, and from the still lower Cambrian fossiliferous sandstones, is arbitrary in those cases where there is no fossil guidance. The Nubian Sandstone extends eastwards to the Hedjaz Railway, and farther to the S.S.E. consists of alternating sands, clays, and marls, which have yielded in one place the fossil *Ostrea olisiponensis* from a calcareous band.

Massive fossiliferous limestones of undoubted *Cenomanian* and *Turonian* age follow on the Nubian Sandstone Series north of the latitude of Ma'an, and with the *Senonian* form practically all the solid rocks of Palestine and Syria. But in Lebanon the stage containing *Trigonia ayriaca* is succeeded by shelly beds of brown chalk with *Trigonia diatana*, *Eorodiolitea plicatua*, and *Enallaster ayriaca*; then comes the ammonite stage containing *Buchiceras* (*Knemiceraa*) *ayriacum* and abundant oysters such as *Oatrea dieneri*, *O. flabellata* and *O. oliaiponenaia*. Some geologists refer all these beds to the *Cenomanian*, but others to the *Turonian*, while Douville suggests they belong to the *Vraconian* on the strength of the echinoid *Enallaater delgadoi*. Above them, in the Lebanon district, come the massive lower Rudistid Limestones or 'Lebanon Limestone,' containing *Eorodiolitea lirata*, *Caprinula cedrorum*, *Nerinea requieni*, etc. The well-known fish-bearing beds of Hakek and Hazhula are interbedded with these lower Rudistid Limestones. The upper part of the Rudistid Limestones belong to the *Turonian*, and contain an ammonite horizon with *Pseudotiaaotia*, *Thomaaita rollandi*, *Mammitea nodosaoides*, and a Hippurite limestone with *Hippuritea reaetua* and species of *Durania*, *Biraodiolitea*, *Nerinwa*, *Actæonella*, *Echinobriaaia*, etc. The ammonite fauna is specially rich in the *Turonian* east of the Jordan^{41 75 78}.

In Palestine proper the development of the *Cenomanian*^{35-37 50 60} and *Turonian* is somewhat different. The lowest beds which are present in Lebanon seem to be wanting, and the whole series of beds is somewhat poorer in fossils and more uniform in petrological characters, so that any well-marked division of the succession is here difficult. The *Cenomanian*⁵⁰, which is divided into an upper and lower stage by argillaceous beds in southern Palestine, mostly consists of limestones and dolomites. In northern Palestine the upper division is strongly developed between Carmel and Nazareth. The *Turonian* is found on both sides of the Dead Sea, as at Engedi, and it forms the upper part of the cliffs south of Tiberias, and much of the cover rock in Samaria as well as of the Judæanarch. On the whole the *Cenomanian* portion is characterised by marly partings between thick beds of limestone or dolomite, while the *Turonian* is marked by uniformly massive and partly siliceous limestones and dolomites rich in remains of rudistids and *Nerinea*. Nodules of flint or chalcodony represent the concentration of the silica. The commonest fossils^{9 11 35 37 41} 42 56 in the *Cenomanian* are oysters (especially *Exogyra mermeti* Coq., *O. flabellata* D'Orb., *O. oliaiponenaia* Sharpe, and *Gryphcea veaiculosa*), and echinoids of the genera *Heterodiadema*, *Holactypua*, *Cyphoaoma*, *Diplopodia*, and *Hemiaater*. The foraminiferal genus *Orbitolina* often forms massive beds⁶⁷, and of bivalves *Eorodiolitea lirata*, *Chondrodonta joanne*, and species of *Cardium*, *Vola*, *Cytherea*, *Pholadomya* etc., occur. A *canthoceraa paleatinenae* Blanck., which is closely allied to *A. rhotomogenae*, is the most widely spread ammonite⁴¹. In the *Turonian*⁵⁰ the chief fossils are echinoids of the genera *Echinobrissus* and *Cyphoaoma*, together with *Hippuritea reaetua*, species of *Nerinea* and *Trochactoson* and the ammonite *Pseudotiaaotia aegnia* Solg, a true African species.

The *Senonian*¹¹⁻¹² varies much in its petrological characters, as it includes grey limestones and marls, white chalk, dark bituminous limestones, phos-

phatic limestones, gypsiferous clays, variegated marls, and beds of flint. There is a rich fauna^{36 39 41 42 50 56 60 66 70} in it comprising *Gryphæa vesicularis*, *Ledaperdita*, *Crassatella syriaca*, etc., and species of *Schlnwbachia* and *Baculites*, and the whole assemblage of organisms resembles that in Egypt and Algeria.

The four divisions, the Santonian, Campanian, Danian, and Maestrichtian can be recognised. The Santonian is developed east of Jerusalem⁵³ and near Safed in Galilee as an ammonite horizon with many species of *Schæbachia*. On the east of Jordan the Santonian is mostly unfossiliferous, but near Madeba contains many north African species of *Ostrea*. The Campanian^{41 42} forms most of the Senonian, and amongst the characteristic fossils are *Ostrea villei*, *Astarte rothi*, *Inoceramus aratus*, *Area parallela*, *Protocardia moabitica*, and species of *Turritella*, *Scalaria*, and *Baculites*. These beds spread far eastward and south-eastward over the Arabian desert.

The *Maestrichtian* is specially developed in the Judæan desert^{50 53} as well as to a less extent elsewhere. It is characterised by asphaltic and phosphatic limestones with thick layers of flint. In the northern part of the area also there is a thin bituminous limestone. (These beds, which were put by Blanckenhorn⁷⁵ and Blake⁵⁰ in the Maestrichtian, are kept by Picard^{53 72} in the Campanian.) The Maestrichtian is marked by an abundance of fish-remains. Other principal fossils are species of *Baculites* *Ptychoceras*, *Libycoceras*, and *Pecten obrutus*⁷⁵.

The *Danian*⁵⁰ consists at the base usually of black bituminous limestone or bituminous shales which are overlain by variegated gypseous chalks and marls, forming the so-called 'mottled zone.' Fossils are few in the Judæan desert, but include *Pecten obrutus*, which occurs with other marine fossils (foraminifera) in white chalk in northern Transjordan. The Danian-Palæocene period is transitional, and the discordances are due to local foldings. Stratigraphically there seems to have been continuous sedimentation during this period, and the only means of separation of the Danian is by the absence of nummulites, etc., which mark the earliest Eocene. The characteristic formation of the whole succession consists of chalk- and flint-beds⁷². In Transjordan the Upper Cretaceous^{50 71 72} is largely developed, and phosphate beds are a feature in the littoral deposits.

Volcanic eruptions took place during Upper Cretaceous times in many parts of Syria, and are represented by basalts of several types, ashes, and tuffs; in Palestine they are specially developed in the Carmel^{50 80} district, at Umm el Fahm, and east of the Dead Sea, near Kerak^{11 22 25 65}.

The Cenomanian-Turonian beds contain iron-ores which have been worked in the past, and the Senonian possesses important phosphatic beds as well as bituminous limestones from which the asphalt and petroleum of the Dead Sea are derived^{22 49}. All the Cretaceous formations yield building stones and marbles⁵⁰.

Cretaceous Earth-Movements.—Towards the end of the Cretaceous⁷⁵ period, according to Picard, there began a series of earth-movements causing the development of anticlinal folds trending south-west to north-east, but mostly short; these axes in southern Palestine change to a more S.S.W. to N.N.E. direction, running up through the central part of the country west of Jerusalem to the neighbourhood of Gilboa⁵⁹.

Tertiary.—The **Eocene**, which has comparatively small exposures in Palestine, principally occurs as massive nummulitic limestones, but is almost everywhere devoid of fossils other than foraminifera. The Eocene beds, which lithologically are like those of the Cretaceous, are now classified by their foraminiferal contents in Palestine^{50 57} and show a sequence from Lower to Upper Eocene. The *Lower Eocene* consists mainly of marls with

subordinate chalks and flints, and are characterised by *Globorotalia* of *velascoensis*, together with *Alveolina*, *Globigerina*, *Orbitolites*, etc. The Middle Eocene is composed of nummulitic limestone and siliceous chalks, with *Nummulites curvispira*, *N. lucasana*, *N. (Camerina) gizehensis*, and species of *Asterocyclina* and *Discocyclina*. The Upper Eocene consists mainly of chalks and chalky marls without flints, and contains *Hantkenina* spp., and *Gumbelina* cf. *ghbuhsa*. The species *Aturia rovasendiana* Parona, which occurs in Egypt and in Italy, has been found in the Upper Eocene of south-western Palestine and near Carmel⁶⁴.

Mounts Ebal and Gerizim⁵⁰ are chiefly composed of Middle Eocene limestones, with flints and nummulites, and show sections like that of the Jebel Mokattam, near Cairo, of Upper Lutetian age. Mount Gilboa^{59 63} also consists of nummulitic limestone and yellow chalk containing varieties of *Nummulites (Camerina) gizehensis*, *Discocyclina*, *Orbitolina*, etc. South-east of Gaza a sandstone, with small nummulites, has been found. Near Nablus two stages can be distinguished, consisting of a lower *Alveolina Limestone* referable to the Lower Eocene, and an upper nummulitic limestone referable to the Middle Eocene. From Gerizim the Eocene extends in a broad belt over Gilboa to the lake of Tiberias, but is broken by faults and much overlain by later basaltic lavas^{65 79 80}. Another elongated patch of Eocene is exposed on the west side of the Jordan farther south between Ras Um Zoka and Karn Sartala. But it is in the valley of the Litany River, and north of Damascus, that the largest exposures occur, and here they consist of narrow folded or faulted bands stretching north or north-east. Isolated small occurrences of Eocene rocks have been observed far in the south of Palestine, as near Ma'an on the east of the Dead Sea on the Hedjaz railway; here numerous fossils have been found, so that its absence now over the greater part of the country seems due to subsequent denudation of the surface.

Oligocene⁵⁸.—Marine Oligocene fossiliferous chalky limestones and marls, crowded in places with foraminifera, and containing also mollusca (especially species of *Pecten*), echinoidea, brachiopoda, polyzoa, etc., occur near Ramleh on the line from Jerusalem to Jaffa^{50 57 58}, and the species *Lepidocyclina (Eulepidina) dilatata* Mich., *L. (Nephrolepidina) toumoueri* Lem. and Douv., with small nummulites of the *A¹. vascus* group are characteristic.

Miocene.—There is a complete absence of Burdigalian beds, but limestones with marine fossils (corals and mollusca) of Helvetian age with abundant *Lithothamnion* occur⁵⁰ and have been found in various localities⁵⁰, such as Tuikarm, and near Beersheba and Gaza⁵⁴. Tortonian beds probably also occur. In Syria⁷⁴ the marine Miocene is more widely represented. In northern Palestine, particularly in the basins of Tiberias-Beisan-Esdraelon, there is, on the other hand, a continental series of fluvialite conglomerates with basalt intercalations in the higher part, succeeded by a lacustrine series, all referred by Picard⁷² to the Middle-Upper Miocene. In the Dead Sea region there are some peculiar beds of disputed age. They constitute the *Jebel Usdum Beds*^{19 20 22 45}, which consist in the lower part of shales, red sands and sandstones, and in the upper part mainly of gypsiferous shales. Below these beds occurs a massive rock-salt deposit, 30-50 ft. thick, with interbedded layers of clay and shale. Picard⁷² compares them with those in the Lower Fars formation of Iran, and considers them to be of Lower or Middle Miocene age, while he correlates the whole Jebel Usdum Series with the Fars; the upper brackish part, however, he considers to be probably of Pliocene age. No fossils have been discovered in these beds. Blake⁴⁹ considered that the whole Jebel Usdum salt deposit and associated gypseous sandstones and marls were 'probably of Pliocene or even older age,' and that they were folded, faulted, and eroded before the deposition of the Pleistocene gravels

and silts. Blake and Wyllie⁴⁵ considered the salt to be intrusive, but Blanckenhorn⁷⁵ regarded its position to be due to earth-movements, for it is stated to be upturned and unconformably overlain by the Jebel Usdum Series. It is to be noted that in Palestine near the end of the Miocene⁴⁸ or beginning of the Pliocene a second period of earth-movement developed which was characterised by fracturing of the crust rather than folding, though monoclinical folds in some places were formed. The trend of the earliest lines of the faulting was oblique to the axes of the earlier anticlines, being meridional. But all through Pliocene and Pleistocene times fracturing in different directions took place.

Pliocene^{33 34 50 53 75 79}.—The oldest Pliocene (Pontian Stage), according to Blanckenhorn⁷⁵, appears nowhere at the surface, but it has been struck in bore-holes in the coastal areas. It consists of bluish-grey clays and marls, and contains mollusca belonging to the genera *Cardita*, *Lucina*, *Venus*, *Cytherea*, *Murex*, *Gibbula*, etc. In the Gaza-Beersheba basin Picard⁵⁴ refers to the Lower Pliocene certain conglomerates, fine-grained sandstones, glauconitic sandstones, and coarse limestones with shell-beds. The Middle Pliocene is developed in the coastal plain⁷⁷, and the most important occurrence is at the north-east foot of Mount Carmel where the bed is a yellowish limestone full of marine mollusca, many of which occur in the Cucullata stage of the Nile Valley in Egypt, corresponding to the Astian in Italy. In the Kishon plain the Middle Pliocene is represented by lacustrine deposits of limestones, clays, marls, and oolitic limestones, containing *Melania* and other fresh-water shells. East of Beersheba the facies consists of reddish or white sandstones and sands, flint-pebbles, and sandy marls, mostly of terrestrial origin; some of the gypsum formations in the Kurnub and Arabah areas may be likewise of Pliocene age. No Astian shore-formations are known to exist north of Ramleh, but in the Haifa plain the bore-holes⁷⁷ and outcrops prove the existence of Plaisancian and Astian beds; in the Esdraelon Plain the Pliocene crops out up to a height of 300 metres above sea-level. In eastern Galilee and the Plain of Jezreel, conglomerates, sandstones, and limestones of Astian age, with many marine fossils^{88 84}, occur, indicating invasions of the sea; but the succeeding brackish lagoon and, finally, terrestrial deposits, prove a continuous shallowing of the water. The Upper Pliocene^{50 67} is represented in the Jordan Valley area by the fresh-water *Melanopsis* Stage¹¹⁵ 22 40 67 75 rich in fresh-water molluscan⁸¹ remains, and comparable with similar inland deposits in Egypt and the Aegean. The beds consist of conglomerates, sands, and marls, and are held by Blanckenhorn⁷⁵ to correspond with the older Glacial stages in Europe. Intense volcanic activity began with the Middle Pliocene marine transgression, and was closely connected with the earth-movements which affected the whole area. It lasted into Pleistocene times, and the basalt-flows^{61 65} of the Hauran, east of the Lake of Galilee and south of Tiberias and at the foot of Mount Tabor, belong to this period of vulcanicity.

Pleistocene and Recent^{82 60 62 72 76 77}.—The marine calcareous sandstones and loose sands^{82 50 76 77} which cover much of the coastal plain belong to this late period and pass up into Prehistoric times. At Atlit⁶⁰ red sands containing Mousterian implements are seen to separate a lower from an upper calcareous sandstone, forming consolidated dunes of Aurignacian age. The history of the Jordan Valley and its post-Pliocene deposits belongs to the Pleistocene and Recent periods, and is described below.

HISTORY OF THE JORDAN VALLEY AND DEAD SEA

The origin and history of the Jordan Valley" 22 81 38 46 48 68 07 72 and Dead Sea have been much discussed for many years⁶³, but the

latest views are those of Bailey Willis^{38 46 48} and Picard^{44 53 67 72}. The whole Jordan Valley^{23 88 44 46 48 72} is due to the subsidence of a long narrow strip of country between several parallel step-faults, which are frequently still marked by fault-scarps. The amount of the vertical displacement is at least 5000 or 6000 ft.¹⁰, though it varies at different parts. The floor of the valley did not sink to an equal extent along its whole course or at the same time, and a higher block was left at the south end of the Dead Sea⁸², which prevented the invasion of the salt waters of the Gulf of Akabah, and is now represented by a diagonal limestone ridge 820 ft. above sea-level. The present level of the surface of the water in the Dead Sea is 1292 ft. below the Mediterranean, but the floor of its basin in its deepest portion sinks to nearly 1300 ft. On the south side of the El Lisan Peninsula the floor rises so that the depth at the southern end is nowhere more than 30-35 ft. There is no evidence¹⁰ that the sea ever found its way into the Dead Sea or Jordan Valley from the south, the end of the valley being closed by this threshold, on the north side of which is the deepest depression of the whole trough, thus constituting the Dead Sea⁸², so that the water, having no outlet, became increasingly saline. But Blanckenhorn³¹ maintains that there is positive evidence of a Middle Pliocene marine invasion of the Jordan Valley from the west by the Mediterranean, to which event the peculiarly high salinity of the Dead Sea is largely due. Picard^{67 72}, on the other hand, considers that its salinity can be explained by the springs and tributaries of the Jordan flowing into it, especially the hot springs of Lake Tiberias, which supply potash and other salts, and belong to the final stage of Pleistocene vulcanism^{61 72}. The salinity⁴⁷ has been further increased by the leaching out of the salt from the surrounding Cretaceous beds, and by a period of great desiccation which followed the formation of the enclosed basin. This dry period, which set in after the dislocation of the Upper Pliocene Melanopsis beds, caused a great evaporation of the water. The present percentage of salts⁴⁹ in the water is over 30 at its south end, but the desiccation has not proceeded as far as it did at this early stage in its history. The salts in the Dead Sea water in relative quantities are successively magnesium chloride, sodium chloride, calcium chloride, potassium chloride, and magnesium bromide⁴⁹.

Following this first dry period there occurred an interval in the Lower Pleistocene of higher rainfall (Pluvial period) which caused the level of the lake to rise to its greatest height, and resulted in the flooding of the whole valley up to the Sea of Merom. At this time were formed the highest of the terraces of the Jordan Valley, of the Dead Sea, and of the Wadi el Arabah. The highest terrace stands 1430 ft. above the present level of the Dead Sea, according to

Huntington⁸, and the beds of rock-salt and lacustrine marls, etc., of Jebel Usdum were at this time covered up by freshly-formed lacustrine deposits. Lacustrine beds at a height of about 1400 ft. have likewise been observed near the Sea of Galilee¹⁰. The length of the great fresh-water lake, or chain of lakes, in which were deposited these high-level sediments, probably exceeded 200 miles from north to south, and had a width of from 8 to 9 miles. The deposits of this *Samra Stage* during 'Pluvial A' consists of gravels, loams, calcareous sandstones, and marls.

A second dry period (the main Interpluvial) then supervened. The lake shrank considerably in size and its level became much lower. At the same time extensive lava-streams flowed down several of the valleys on the eastern side of the Dead Sea, as in Wadi Zerka and in the Jarmuk Valley, and sheets of lava spread over the Hauran and Galilee.

Another increase in the rainfall marks a second or Pluvial period B; the level of the water rose again, but not to its previous height, and resulted in the formation of the middle group of terraces at heights of 540, 430, 300, and 250 ft., according to Huntington⁸. Some subsequent warping has caused their present elevation to show slight variations of level. This Pluvial B period is termed the *Lisan Stage*^{40 53 67 80}, and is regarded as of Middle Pleistocene age; during it the above-mentioned Lisan marls and gypsum deposits were laid down. In the centre of the basin at the north end of the Dead Sea the beds are at least 450 ft. thick, and apparently extended as far north as Tiberias. Picard⁷² maintains that the oldest terrace belongs to the Upper Pleistocene and none to the Middle. The periods of deposition and erosion are related to the earth-movements in this region. On the sea coast the Mediterranean advanced and deposited the shelly oolitic calcareous sandstone of Gaza and Jaffa, as above mentioned, upon the earlier-formed deposits of the same character. Further volcanic eruptions of basalts^{25 61} and tuffs took place in the Jarmuk and Zerka Valleys.

A third dry period succeeded at the beginning of the Upper Pleistocene, but it was marked by minor climatic pulsations which produced oscillations in the level of the great Jordan Valley lake, and this has continued down to the present day. Implements of the Chellean⁷² type are found in many places on the surface of the high plateau and in the valleys^{22 50 52}. The correlation of the Pluvial and Interpluvial stages with those of the human artefacts found in the terraces and elsewhere⁸⁵ is disputed, but Picard⁷² puts the Chellean stage in the Pluvial period A. Some of the terraces in the valleys are of still later date and belong to historic times⁸. Huntington recognises ten strands below the 250-ft. beach

at heights ranging from 210 ft. to 12 ft. above the present water-level.

Blanckenhorn^{1 2 24 50} attempts to correlate the above-mentioned various dry and wet periods of Palestine (as indicated by the whole series of terraces) with the Glacial and Interglacial periods of northern Europe, referring the Melanopsis stage to the Gunz Ice-age, the Great Pluvial period A to the Mindel Ice-age, the Little Pluvial period B to the Riss Ice-age, and the lowest terraces partly to the Wurm Ice-age; but his conclusions, which are quoted by Blake⁵⁰, are open to question.

The latest crustal movements, which began^{40 53} early in Quaternary times, affected not only the Jordan Valley and Dead Sea, but also the Red Sea. The Lisan beds were then elevated over 700 ft. above the Dead Sea. In northern Palestine the whole of Mount Carmel shows that similar late movements raised it high above the surrounding region; the mountains of Samaria were also involved in these movements. Earth-movements have continued to take place during historic times, probably along the old lines of fracture, and have manifested themselves from time to time, up to the present, in earthquakes of considerable intensity.

The date of the latest volcanic eruptions^{11 61} is doubtful, but that it was comparatively recent in places is proved by the lavas having overflowed the gravels in many of the *wadis* on the east side of the Arabah and Dead Sea, and by the fresh appearance of the volcanic materials. The presence of hot springs^{20 49} depositing sulphur, etc., in their vicinity, as in the Wadi Zerka Main on the Dead Sea and on the Lake of Tiberias, is probably a symptom of dying or dormant volcanic activity.

With regard to recent superficial accumulations, the calcareous surface rock¹² known as 'Nari,' which is found over wide areas, is a reddish limestone containing fragments of surface rocks, especially flints, and is partly due to rain wash from the Cretaceous limestones, and partly to capillary action in conjunction with intense desiccation.

ECONOMIC GEOLOGY[^]

Copper.—South of the Dead Sea at Ratijje, near Fenan, ores of copper (malachite, etc.) occur in the Cambrian sandstones, and have been worked in the past²².

Iron.—Iron-ore occurs in the Cenomanian limestone on the east of Jordan, near Jerash, in the Cambrian south of the Dead Sea, and in the Nubian Sandstone and the Jurassic of Lebanon, but the occurrences seem to be of small value.

Sulphur⁴⁹.—The occurrences of layers of nodules of sulphur^{22 72} and gypsum in the chalky marl of the lower terraces in the Jordan Valley near Jericho, on the Lisan Peninsula in the Dead Sea, and elsewhere, seem due to the action of hot springs²⁰ which occur at various points along the fault-lines, and have their waters frequently charged with sulphuretted hydrogen.

Asphalt and Petroleum^{49 82} are found in many parts, but especially on the east side of the Dead Sea⁸² at Ain el Hommar²², where pitch and naphtha springs also are said to occur, apparently in Cretaceous sandstone. On the west side asphalt oozes out of the Senonian at many places, and the limestone and marls at Nebi Musa are rich in bitumen²². The Senonian^{1 2 20 50} beds are often impregnated with this substance, and it occasionally forms the binding material of the conglomerates of some of the middle gravel-terraces of the Jordan Valley, or fills fissures in the solid rocks.

Salt and Gypsum^{49 50}.—Beds of salt and gypsum of commercial importance occur in the Cretaceous, but the most important deposits are in the Jebel Usdum at the south end of the Dead Sea, where they are associated with gypseous marls and sandstones of Miocene or Pleistocene age^{45 47 49}.

Phosphates⁴⁹.—On the west side of the Jordan, in the Judæan desert⁵³, between Jerusalem and Jericho, there are richly phosphatic beds of chalk (Campanian) having a percentage of tricalcium phosphate up to 53 per cent., and on the east side on the Siru Plateau²², at Ain Hommar, there are considerable deposits of phosphate in the Senonian with from 40 per cent, to 80 per cent, of phosphate.

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