A SUMMARY OF THE GEOLOGY OF INDIA.

BY

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A.R.S.M., A.R.C.S.

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OF THE

GEOLOGICAL SURVEY OF INDIA

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AS A

SMALL TRIBUTE OF APPRECIATION,

THIS WORK IS

DEDICATED TO

MR. R. D. OLDHAM,

WHO INITIATED THE AUTHOR INTO THE STUDY OF

INDIAN GEOLOGY.

ERRATA.

Page.		Instead of	Read.
4,	last line but one,	Fermer	Fermor
17,	last line	Chiep	Chilpi
32,	5th line from bottom,	Fenstella	Fenestella
52,	4th line from bottom,	*Hiteroceras*	*Heteroceras*
61,	last line but one,	*Mastedon*	*Mastodon*

In the second page of the Table of Geological formations at the end of the volume, the word "PATCHAM" should be raised to the same level as "Massive limestone."

INTRODUCTION.

Peninsular, extra-peninsular, and Indo-Gangetic regions.

FROM a geological point of view India is divided into three regions, (1) the peninsular area in which there are no mountains in the true sense newer than palæozoic, (2) the region of relatively recent mountains (tertiary in age), constituting the ranges of the Himalaya, Baluchistan and Burma, and (3) the great Indo-Gangetic alluvial plain. These divisions are intimately connected with the physiographical history of the countries that now constitute the Indian Empire. In the Peninsula all the rocks of Upper Palæozoic age, or newer, are either horizontal, or dipping at comparatively low angles. The principal type of disturbance that has affected the peninsular area during the Upper Palæozoic and later times is the formation of elongated almost rectilinear trough faults which are of paramount importance in the mineral resources of India, as they account for the formation and preservation of the Indian coal-basins. The central and western portion of the peninsular area is occupied by an enormous outcrop of heavy, black, volcanic rocks known as the Deccan Trap. It constitutes flat-topped hills, built of piled-up flows of basaltic lava, which have remained almost undisturbed since they were erupted in cretaceous times. The faulted troughs constituting the coal-basins occupy relatively small areas, principally in the eastern and north-eastern part of the peninsular region. Outside of these coal-basins the rocks constituting the peninsular area, wherever they are not concealed by the Deccan Trap, are mostly of palæozoic or older age, with the exception of a fringe of cretaceous and tertiary strata at some points along the sea-coast. These later beds, found in the neighbourhood of the present sea-coast, are the only fossiliferous marine sediments of the peninsular area. The

absence of such beds from the remainder of the peninsula, indicates that this portion of India has been a continental area ever since the earliest geological times, and is one of the oldest land areas of the globe.

The rocks constituting the extra-peninsular area, that is the mountain ranges of the Himalaya, of Baluchistan and of Burma, contain, in addition to a substratum of rocks identical with some of the older ones of the Peninsula, numerous representatives of marine fossiliferous strata of almost every geological age from Cambrian to Tertiary. The area remained occupied by the ocean until late in Tertiary times, when the upheaval of the Himalaya was completed.

The great Indo-Gangetic plain, which now joins together the essentially different peninsular and extra-peninsular areas, consists of alluvial soil mostly derived from the disintegration of the Himalaya, whose rapid accumulation has finally obliterated all remnants of the arm of the sea which might still have subsisted between the two areas.

The geological formations of India may be classified into the following divisions :

Recent formations.
Pleistocene.
Siwalik System (Pliocene and Upper Miocene).
Pegu or Mekran System (Lower Miocene and Oligocene).
Eocene.
Mesozoic or Secondary.
Permian and Upper Carboniferous.
Lower Carboniferous and Devonian.
Silurian, Cambrian, and Pre-Cambrian.
Oldest Sediments.
Fundamental Gneiss or Archæan.

A word of explanation may be given to account for the manner in which two of the geological divisions, the Miocene and the Carboniferous, have each been split

into two portions separately joined to the preceding and succeeding horizons. This does not imply that the geological periods are distributed differently in India to what they are in other parts of the globe. The reason is that the geological nomenclature has been largely founded on palæontological data without any very special reference to the leading episodes in the physical evolution of the globe. Modern geological researches have been largely directed towards accurately defining the exact position that these great physical changes occupy in the geological scale, but it has not been thought necessary to alter the already established nomenclature so as to make it fit into these geological landmarks, a process that would risk causing confusion. Nevertheless, it is these physical breaks that are especially useful to the geological surveyor in a new country. In a land like India, where geological investigation is comparatively little advanced, the main divisions have been framed principally in accordance with the physical breaks. Although there is usually no difficulty in deciding whether a particular bed is newer or older than the Middle Miocene, or than the Middle Carboniferous, great uncertainty remains as to whether certain strata amongst the Siwaliks are to be referred to the Upper Miocene or to the Pliocene, or whether certain portions of the Lower Gondwana should be referred to the Upper Carboniferous or Permian. The use of local terms, such as those just mentioned, partly obviates this difficulty. But as there does not exist any consistent scheme of local nomenclature that will apply to the whole of the Indian Empire, I have omitted such names from the tabulated outline of the main divisions above given, especially as, with each advance of our knowledge, the local terms must one by one give way to those of the international nomenclature. A number of these local terms will be defined in the subsequent portions of this note.

THE ARCHÆAN.

THE Archæan, if one restricts this name to the rocks underlying the oldest undoubted sediments, consists essentially of crystalline gneissose rocks that must have solidified under conditions quite different from those that attended the formation of later rocks. These gneisses represent, in part at least, the original crust of the globe, when the surface of the originally molten mass first began to solidify.

As in other parts of the world, the Archæan system in India is largely made up of rocks whose composition and structure resemble those of the intrusive rocks of the family of the granites or diorites—granular aggregates of quartz, felspar (silicate of alumina and of alkali or lime), and various ferro-magnesian silicates, such as amphibole, mica of certain kinds, or less frequently pyroxene. These rocks differ from many of the true intrusive granites and diorites of later ages owing to the pronounced parallel arrangement of their constituting minerals, producing the structure known as gneissose. In addition to the parallel arrangement of the minerals within the rocks, the whole mass is often arranged in parallel layers of rapidly varying composition. In some of these rocks felspar is scarce or absent, and thus they pass from the condition of gneisses to that of crystalline schists. Amongst the most peculiar types of this class are the sillimanite schists of Orissa discovered by Dr. Walker and named by him "khondalites" (Memoirs of the Geological Survey of India, Vol. XXXIII); also the corundum bed of South Rewa, in Central India; the manganiferous garnet-bearing schists and gneisses discovered by Mr. L. L. Fermer, and called by him the "kodurites." There are many outcrops of garnetiferous mica schists.

It is sometimes uncertain whether these schists are true members of the Archæan system, or metamorphosed representatives of some of the subsequent normal sedimentary series.

Where rocks have been subjected to the combined influences of intense pressure and high temperature, as in the sharply folded synclines of mountain systems, they acquire a schistose banded crystalline structure which may render them very similar in appearance to the Archæan gneisses, especially where, as is often the case, granitic and dioritic intrusions are interleaved with them. Uncertainties of this sort can usually be settled by following the outcrop to a region where the rocks are less metamorphosed, or by observing the stratigraphical relations of the doubtful rocks to others belonging to some well-established geological system. In the case of the "khondalites" of Orissa, neither of these methods is available, and consequently, in the present stage of our knowledge, their true position remains somewhat doubtful, though the balance of evidence is in favour of their being regarded as members of the Archæan.

Three well-marked types have been recognized by the Geological Survey of India amongst the rocks of the Archæan. These are: the BENGAL GNEISS (Oldham, Memoirs of the Geological Survey of India, Volume I, 1859), the BUNDELKHAND GNEISS (Mallet, Manual of the Geology of India, p. 10, 1879), and the NILGIRI or MOUNTAIN GNEISS (King, Mem. G. S. I., Vol. XVI, p. 125, 1880).

Bengal Gneiss.

The Bengal Gneiss is characterized by its varied composition and conspicuously banded structure. It often exhibits rapidly alternating layers of sharply contrasted composition, some of which exhibit the characters of gneissose granites and diorites, while others are more of the nature of schists. The schistose types are very numer-

ous, including quartzose, micaceous and hornblendic schists, garnet-bearing, magnetite-bearing, sillimanite-bearing, and manganiferous gneisses and schists, such as the khondalites and kodurites already mentioned, and many other varieties.

Bundelkhand Gneiss.

The Bundelkhand Gneiss, which, in its type area, usually has the appearance and composition of a coarse typical pink granite, was once regarded as the oldest rock in India. At a time when gneisses were regarded as metamorphosed sediments, the coarseness of crystallization was thought to be related to the degree of metamorphism, and consequently to the antiquity, of the rocks. As the oldest rocks of the earth's crust must include representatives of its first definitive consolidation from its original molten condition, it is evident that the Archæan must consist largely of rocks formed under conditions different from any with which we are acquainted in the present stage of the globe's history. The Bundelkhand Gneiss, when the nature and composition of the rock are considered, closely resembles an intrusive granite, but differs from undoubtedly genuine granitic intrusions owing to the enormous area which it occupies. When the Archæan rocks first consolidated, the primordial atmosphere contained in the state of vapour the totality of the water that now forms the ocean, the volatile chlorides, as well as a large proportion of the carbonic acid and oxygen that have now been absorbed by various solid rocks. It is quite conceivable that under the enormous pressure of this primordial atmosphere, molten masses may have spread out over large areas, and on solidifying assumed the granitic form which at later periods could only have been developed under similar conditions of pressure and temperature in the depths of the earth's crust. Instead of being older than the Bengal Gneiss, it is quite possible therefore that the Bundelkhand Gneiss may be resting

on a substratum of previously solidified rocks. Much of the banded structure of the Bengal Gneiss is due to the injection of molten rocks in the midst of previously solidified gneisses or schists. Some of these intrusions may be contemporaneous in age with the outflow of the Bundelkhand Gneiss. Thus, the Bundelkhand Gneiss, instead of being the oldest rock of the peninsula, may be newer than some parts at least of the Bengal Gneiss.

In the present state of our knowledge it is not possible to define exactly the chronological relations of these two types. Nevertheless, it is evident that they are amongst the oldest rocks of the globe—those constituting the series often spoken of as PRIMORDIAL or FUNDAMENTAL GNEISS.

Whenever the Bengal Gneiss is contiguous to an outcrop of some other geological series, the latter almost invariably contains rocks that resist weathering better than the gneiss itself, which consequently occupies the lower ground, the adjacent harder series standing out as hills. When the Bengal Gneiss, unaccompanied by any other geological formation, spreads over an extensive region, it is apt to constitute hills usually of somewhat rounded outline.

Where granitoid bands of appreciable width constitute part of the Bengal Gneiss, they weather into the characteristic groups of piled up blocks of huge dimensions known as "tors." The same mode of weathering affects the Bundelkhand Gneiss. In its type-area, the Bundelkhand Gneiss constitutes principally a plain, surrounded by cliffs of the much harder Vindhyan sandstones. This plain is traversed by great rectilinear, wall-like ribs of quartz constituted by huge veins of that substance many miles in length. They give rise to rugged hills, imparting quite a special character to the scenery of Bundelkhand, and affording great facilities for the creation of artificial lakes.

Quartz-veins of Bundelkhand.

Distribution of Bengal Gneiss and Bundelkhand Gneiss.

Lower Bundelkhand is the principal area of this form of gneiss in Northern India. The Bengal Gneiss occupies large surfaces in Behar, Manbhum, Orissa, Rewa, the Dhar Forest, and Gujrat. As regards Southern India, so far as can be made out from published accounts, the schistose gneisses that have been described as Karnatic Gneiss or Salem Gneiss, seem to correspond with the facies of the Bengal Gneiss, while the facies of the Bundelkhand Gneiss recalls that of the massive granitoid red gneiss which prevails in the upland of Southern India and has been distinguished under various names such as Bálághát or Hosur Gneiss. Its eastern confines from the Palár to the Kistna are almost continuous with the edge of the ghâts, and it is typically developed in North Arcot, in the Kadapah subdivision, in the eastern part of the Bellary district, where it is traversed by gigantic quartz veins similar to those of Bundelkhand, in the Karnul district, and thence all over the eastern portion of the Hyderabad Territory up to the higher reaches of the Godávari river. It has been largely used as a building material throughout Southern India. The magnificent buildings of Vijayanagar, in particular, are constructed of Hosur Gneiss.

Central Gneiss of Himalaya.

The Central Gneiss of the Himalaya is in part at least of Archæan age, but in the present state of the survey cannot always with certainty be distinguished from intrusive granites of Tertiary age; neither are the available descriptions sufficient to tell whether the Bundelkhand Gneiss or Bengal Gneiss facies is more particularly represented. Still more scanty is our knowledge regarding the Fundamental Gneiss in the Burmese and Malay region, though the system is there also represented.

Nilgiri Gneiss.

The gneisses constituting some of the principal hill masses of the Deccan, such as the Nilgiris, the Palnis and the Shevaroys, also closely resemble intrusive rocks except for the greatness of their outcrops. They are granitoid rocks of a peculiar dark-grey to black colour, and their distinctness from the other rocks of the Peninsula was first recognized by the late Dr. King, who proposed for this series, the appropriate name of "Nilgiri" or "Mountain Gneiss."

The same rock is also observed near Madras and in the tributary mahals of Orissa, and in the districts of Ganjam and Vizagapatam. The leading features of these rocks are their dark colour and the constant presence of the mineral enstatite (essentially silicate of magnesia). They also frequently contain garnet. Some varieties contain quartz, others do not, but even when there is a high proportion of quartz, this mineral assumes a dark bluish colour, which does not affect the general dark tinge of the rock, producing a very different appearance from that of the more familiar types of quartz-bearing rocks, such as ordinary granites and diorites. The heavier and less siliceous types of the Nilgiri or Mountain Gneiss belong to the class of rocks known as "norites," while the more siliceous ones come nearer to the composition of diorites and granites, from which they differ nevertheless owing to an unusually high percentage of magnesia and ferrous oxide, and by the presence of enstatite, a mineral characteristic of rocks that have a low percentage of silica, but generally absent from the usual types of highly siliceous rocks, such as normal granites or diorites. Amongst these enstatite-bearing rocks, the types that most nearly approach a granite in composition have been called by Mr. T. H. Holland "charnockites," because the tombstone of Job Charnock, the founder of Calcutta, consists of a slab of that rock: the material is much

Charnockite.

appreciated as an ornamental stone, owing to its handsome granular appearance and dark colour.

Anorthosites of Bengal.

Somewhat related in composition to the Nilgiri Gneiss, and perhaps belonging to the same geological system, are the anorthosites of Bengal, so called on account of their being largely made up of lime-bearing felspars related to the mineral Anorthite.

In some parts of Southern India, rocks regarded as identical with the Nilgiri Gneiss are said to be intruded amongst folded and metamorphosed sedimentary beds corresponding with the Dharwar Series. The latter identification owing to the degree of metamorphism is open to question, and the rocks may be schistose representatives of the Bengal Gneiss. Moreover, even if the folded beds were unquestionably of Dharwar age, this would not suffice to prove that the apparently intrusive rock is newer. In the deepest portions of these ancient folds, solid rocks seem to have recovered a certain amount of fluidity and to have reacted upon one another, simulating the effects of contact metamorphism, although there may not have been any real intrusion. In Southern India, where the Hosur Gneiss, the local representative of the Bundelkhand Gneiss, comes into contact with the Nilgiri Gneiss, there is some evidence pointing to their being both of about the same age, while we have the direct evidence of stratigraphical superposition to prove that the Dharwars, the local representatives of the oldest sedimentary system, are newer than the Hosur Gneiss.

Thus, although the investigation is not yet complete, there is every reason to regard the Nilgiri Gneiss as a member of the Archæan System, either of the same age as the Bundelkhand Gneiss, or somewhat newer.

The three principal divisions of the Archæan of India can, therefore, be tabulated as follows :—

NILGIRI OR MOUNTAIN GNEISS, including dark-coloured enstatite-granites or granulites ("charnockites") and other dark-coloured crystalline rocks of intrusive appearance, both with and without quartz, characterized by the abundance of the mineral enstatite; also the anorthosites of Bengal.

BUNDELKHAND GNEISS, with the Bálaghát or Hosur Gneiss, and other granitoid gneisses.

BENGAL GNEISS, including schistose and banded gneisses, and various rocks of metamorphic appearance and doubtful origin, such as the khondalites, the iron ores of Salem, etc.

OLDEST SEDIMENTARY SYSTEMS.

After the consolidation of the original crust of the globe now constituting the Archæan rocks, a time must have come when the temperature was sufficiently lowered for the vapours contained in the primordial atmosphere to condense and form the ocean. Subsequently to this event, the temperature of the earth's crust could no longer vary except within narrow limits, while the temperature of the inner core of the globe continued slowly to decrease, and is still decreasing at the present day. In order to adjust itself to the contraction in volume which results from this gradual cooling of the earth's interior, the outer crust became corrugated into ridges and furrows. The inequalities thus arising in the earth's figure became gradually more pronounced, and at last some of the troughs absorbed so much of the bulk of the waters, that the general level of the ocean surface sank below that of the highest ridges or bulges. In this manner the first continents appeared, and as their surface became at once degraded by atmospheric agencies, true sediments began to accumulate in the neighbouring parts of the ocean. The gradual deepening of the ocean, and the consequent expansion of the continents, by raising these earliest sediments above the sea-level, accounts for their rapid removal by denuding agencies. Consequently they have now almost everywhere disappeared, except where portions of them have been caught up amidst the folds of subsequent corrugations, such as those which accompany the formation of mountain ranges. The increased depth and thickness resulting from this compression has saved some of these folded portions from being completely removed by denudation. This is why the oldest sediments of the globe

are almost entirely restricted to narrow highly compressed synclines. Consequently their outcrops assume the appearance of more or less parallel narrow elongated strips, such as is particularly well shown in the Dharwar region of Southern India. It is the deepest parts of the original synclines that are thus preserved, precisely those parts where the combined effects of compression and heat have produced the most intense degree of metamorphism, and as this is often enhanced by the contact effects of igneous intrusions, a crystalline facies may be produced which it is sometimes very difficult to distinguish from that of certain forms of Archæan gneisses.

Amongst the most characteristic rocks of the oldest sedimentary system of India may be mentioned: hæmatite-schists, magnetite-bearing schists and massive beds of hæmatite and magnetite; massive beds of manganese ore; a great variety of more or less altered volcanic beds, largely basic; hornblendic schists, which probably represent metamorphosed volcanic flows or intrusive sills, various kinds of highly magnesian rocks, such as talc-schists, serpentinous limestones, potstones; highly crystalline limestones and dolomites, passing into scapolite-gneisses and pyroxene granulites, which appear to be the result of metamorphism from associated granitic intrusions.

Single outcrops of this ancient sedimentary series, as a rule, do not contain every one of these forms of rocks, but they always combine a sufficient variety of them to lend to the formation its characteristic facies. The bulk of the formation usually consists of a considerable thickness of slates showing every passage through chiastolite-bearing slates and semi-crystalline phyllites to typical mica schists often with the development of andalusite and garnets. When the slates are but slightly altered, they are not readily distinguishable from those of some less ancient series of the

Peninsula, the Kadapah system for instance; but they frequently exhibit the altered schistose facies over large areas with a degree of metamorphism which is only observed quite locally, if at all, amongst the rocks of Kadapah age.

Granitic intrusions varying in size from large bosses to narrow veins are a frequent feature amongst the outcrops of the oldest sediments. Some of the finely foliated mica schists are, as it were, impregnated with narrow strings of intrusive granitic material, the combination thus produced giving readily the impression of a gneiss.

Such instances, as also those of the highly crystalline scapolite-gneisses and pyroxene granulites resulting probably from the combined influences of dynamic and contact metamorphism, as also the existence of large outcrops of highly crystalline mica schists are amongst the circumstances that tend to produce confusion between genuine Archæans and altered sediments. Instances have been observed, however, where a direct connection can be traced between outcrops of highly metamorphosed rocks and others in which the alteration is of a much slighter degree. Of particular interest in this respect is the belt that extends east—west from the neighbourhood of Midnapore to that of Nágpur. In the eastern part of the outcrop, in Chota Nágpur, the series consists of unmetamorphosed slates, sandstones and limestones, dipping at low angles and spreading over a broad area. Further west, towards Raigarh and Bálághát, the outcrops assume the usual narrow synclinal structure. The unmetamorphosed slates are gradually replaced by phyllites in Bálághát district, and by schists and gneisses in Nágpúr district.

Amongst the various rocks of the system, the massive beds of manganese ore and the still more massive iron ores are the most characteristic. Similar rocks

occur in some of the divisions of the succeeding Kadapah, but never in such bulky masses. The brilliantly coloured banded jaspers are amongst the most conspicuous rocks of the oldest sediments, but they are equally well developed in the succeeding Kadapah. The crystalline limestones, which constitute ornamental stones of unrivalled excellence, are very characteristic of the older system.

Banded jasper.

Constituting as they do the earliest products of the redistribution of disintegrated material, the sandstones or quartzites of this ancient system do not exhibit a sorting of the constituent minerals of the original gneisses comparable to that observed in sandstones of later date which usually represent the results of several cycles of denudation. Hence they are often of the nature of an arkose, and usually very felspathic. In some cases the felspar has been subsequently decomposed, leaving an aggregate of interlocking grains of quartz that constitutes the curious flexible sandstone of Kaliána, near Dadri in Jind.

Flexible sandstone.

With the exception of the rather broadly spread-out exposure in Singhbhúm, all the occurrences of the oldest system exhibit, as already mentioned, the structure of groups of narrow synclines, indicating the position of old mountain ranges, most of which have been so thoroughly effaced by ages of continuous denudation, that they have lost all topographical individuality. It is only in the case of the Aravalli that they still form a very distinct geographical feature, probably because the upheaval of this range was partly renewed in later times.

It is the Aravalli range that exhibits these rocks in their greatest variety. They have been grouped into several divisions (Raialo, Ajabgarh, etc.). The continuation of the Aravalli outcrop in Gujrat is known as the Champaner series. Another outcrop, probably

of the same series, occurs further east, near the town of Bág, north of the Narbada. Still further east, further up the course of the Narbada, there are some very typical outcrops of the same system in the neighbourhood of Narsinghpur and Jabalpur. The well-known "Marble Rocks" near the latter town belong to it. Various names have been applied to different parts of this outcrop, such as Chanderdip, Majauli, Lora, but just as in the case of the names given to portions of the Aravalli range, they are also merely of local value. A further extension of this outcrop is found south of the Son in Rewa. The same rocks also constitute the Karakpur hills of Behar, where the slate beds which they contain are extensively quarried. The outcrop extending from Midnapore to Nágpur has already been noticed. In the Bálághát district, they have been described under the name of Chilpi Ghat Series. Another outcrop of the same rocks occurs in Bastar territory. In Southern India, a large number of outcrops have been described under the name of Dharwar Series, the most famous being the synclinal exposure situated in Mysore, that contains the Kolar gold-field.

The same rocks are found in the Assam plateau where they have been described as the Shillong Series. In the Himalayan region, the same rocks are known as the Daling Series in the Eastern Himalaya, Jaunsar Series in the Chakrata region, Infra-Krol (in part) in the Simla region, Vaikrita in Spiti, Panjal (in part) in the Western Himalaya.

The same system constitutes the Miju ranges at the head of the Assam Valley, and is largely developed in Burma, where the crystalline limestones, containing the rubies and other gems, perhaps belong to this period.

Of the numerous names that have been used by Indian geologists for designating this series, the earliest in date is Champaner (Blanford, 1869), the latest and most popular is Dharwar (Foote, 1886), the most

suitable is Aravalli (Hackett, 1877), as it is derived from one of the most remarkable and one of the oldest physical features of the globe. There is super-abundant evidence, however, that these rocks correspond with the system known in other parts of the globe as the Huronian, and the use of a local designation for the Indian area is therefore superfluous.

Intrusive granites and pegmatites.

Amongst the rocks that are intrusive in these ancient Aravalli or Dharwar beds, yet undoubtedly older than the overlying Kadapahs, may be mentioned granites, which are of medium grain when the intrusion assumes the shape of a compact boss, as in the case of the rock known as dome-gneiss in Hazaribagh, but which become extremely coarse-grained pegmatites when the shape of the intrusion becomes that of a comparatively narrow dyke. When the pegmatites traverse mica schists, they usually contain marketable mica, as in the pegmatite veins of Rajputana, Hazaribagh and Nellore.

Elæolite-Syenites.

Another group of intrusions, probably of the same age, consists of some very interesting rocks containing minerals of the group of the felspathoids, such as the elæolite-syenites discovered by Mr. T. H. Holland at the Sivamalai hill in Coimbatore, and by Mr. Middlemiss in the Vizagapatam hill tracts, and the elæolite-sodalite-syenites discovered by Mr. Vredenburg in the Aravalli range. This is perhaps also the age of the "dunites" (rocks rich in chrome and magnesia) of the Salem district.

Quartz-porphyries.

A very interesting set of igneous rocks closely connected with this oldest sedimentary system, but whose exact mode of occurrence has not yet been elucidated, is a series of quartz porphyries sometimes resembling rhyolites and andesites that are particularly abundant in the Aravalli, Chiep, Daling and Jaunsar

exposures. Whether they belong to the same series as the granite bosses and pegmatite veins, or whether they represent intrusive sills and flows of a truly contemporaneous volcanic system is a matter that still remains unsettled. Volcanic rocks of a somewhat similar appearance are also found in the much later Vindhyans, but in much smaller proportion. Dykes of closely similar quartz porphyries traverse certain Archæan areas in vast numbers, but they have not been observed cutting through the Kadapahs or Vindhyans. They are probably related therefore to the sills or flows observed in the Aravallis and Chilpis.

Auriferous veins.

At a period that is not exactly known, numerous fissures were formed in these ancient rocks, which became subsequently filled by quartz impregnated with metallic minerals, producing mineral veins, the richest amongst which are those containing gold and copper.

THE KADAPAH SYSTEM.

THE orogenic effort that folded the Aravallis, Dharwars, and other ancient rocks, has powerfully affected the Indian Peninsula. Later efforts of the same kind have been comparatively feeble, the latest of these not being later than the Older Palæozoic era. Since Older Palæozoic times, the Indian Peninsula has no longer yielded to distinct corrugation, and has behaved as a rigid portion of the earth's crust. The main periods of orogenic effort have been practically synchronous all over the world, and are of great assistance in identifying rocks with one another in distant parts of the world, especially when the rocks are unfossiliferous or nearly so.

Two main periods of orogenic effort have affected many parts of the world during the Palæozoic, one in Silurian times, and the other in the Middle Carboniferous. The Peninsula has been affected by one or perhaps both of them, though in a much slighter degree than by the great post-Huronian upheaval. But the total absence of any fossils, so far as has been observed in beds older than Upper Carboniferous in the Peninsula, introduces an element of doubt in their correlation.

The extra-peninsular regions contain these same unfossiliferous groups recognizable from certain petrological peculiarities, and, at the same time, they also contain fossiliferous beds ranging in age from Cambrian to Middle Carboniferous; unfortunately, the fossiliferous and unfossiliferous exposures are not contiguous. In the present state of our knowledge, therefore, the fossiliferous and unfossiliferous exposures cannot be linked together, and will have to be treated separately, though it is quite possible that the two series partly correspond with one another.

The bulk of the Kadapah system consists of shales and limestones. Slaty cleavage, varying in degree, is often observed in the shales, but the limestones never acquire the crystalline texture that is so common in the Aravalli system. As might be expected, the Kadapahs are intermediate between the older Aravallis or Dharwars and the newer Vindhyans, not only in point of the degree of alteration, but also in the nature of the rocks constituting the two groups, the shales which are often calcareous, and the somewhat thin-bedded limestones are essentially similar to those of the Vindhyan formation, but the Kadapahs also contain some of the characteristic Huronian rocks, such as the manganese and iron ores, and the banded jaspers. It is only the latter, however, that are equally well represented in both formations. These bright-red jaspers have been extensively used in the inlaid decoration of the buildings of Delhi and Agra.

There are two main divisions of the Kadapah, each consisting of several series separated from one another by unconformities. The rocks resembling some of the Huronian beds, such as the banded jaspers, are especially abundant in the Lower Kadapahs, while the Upper Kadapahs are more like the Vindhyans. Amongst the Upper Kadapahs, one sometimes notices some remarkable conglomerates or rather boulder-beds, consisting of pebbles of various sizes, some of them very large, scattered through a fine-grained slaty or shaly matrix. Similar beds are found in the pre-carboniferous rocks of South Africa and Australia, and correspond perhaps in age with the Indian ones. These peculiar boulder-beds are regarded as glacial in origin. The best known example of the type occurs at a somewhat higher horizon, constituting the Talchir conglomerate at the base of the Upper Carboniferous.

Boulder-beds.

Of the two sub-divisions of the Lower Kadapah,

the lowermost known as the Papaghni Series has been observed only in the type area of the Kadapah system in Southern India. The upper member of the Lower Kadapah, known as the Bijawar Series, is widely distributed throughout India, and is easily recognized on account of its association with a grand volcanic outburst, the products of which consist of basic lavas, sills and ash-beds intercalated amidst the Bijawar sediments, and intrusive dykes and bosses of the same composition penetrating through rocks of greater age than the Bijawars. These dykes are interesting as being probably the original home of the Indian diamonds, now found as derived pebbles in the later Vindhyan conglomerates.

Volcanic rocks of Bijawar Series.

The Bijawars were first described in the State of that name in Bundelkhand (Medlicott, 1860), and were subsequently identified south of the Son River in Rewa, and north of the Narbada River in the Dhar Forest. In the type area of the Kadapahs, where their identity with the Bijawar Series was not at first recognized, they were described under the name of Cheyair, and near Gwalior they were called the Gwalior Series. The Penganga beds of the Pránhitá Valley also appear to belong to this same horizon.

The Upper Kadapahs are represented in the type area of the Kadapahs by the Nallamalai and Kistna Series, by the Kaladgi beds between Belgaum and Kaladgi, by the Pakhals of the lower Godaveri. They are represented in Rewa State south of the Son River, and round the Chhatisgarh basin.

In the Himalayan region, the representatives of the Upper Kadapahs are the Baxa beds in the Eastern Himalaya, and the Blaini beds in the Simla region. The Haimantas of Spiti are very similar lithologically to the Upper Kadapahs. They underlie beds of Upper Cambrian age.

The general scheme of classification of the Kadapahs is as follows :—

UPPER KADAPAH, including the Nallamalai overlaid by the Kistna Series, the Kaladgi Series, the Pakhal Series, the older beds underlying the Vindhyan of the Chhatisgarh basin, some beds intervening between the Vindhyans and Bijawar, south of the Son; the Baxa, Blaini, and probably the Haimanta Series of the Himalaya.

LOWER KADAPAH, BIJAWAR SERIES, including the Bijawars of Bundelkhand, of the Son Valley and the Dhar forest, the Gwalior, the Penganga, and the Cheyair Series, and numerous basic volcanic rocks.

PAPAGHNI SERIES.

Throughout the greater part of their outcrops, the Kadapahs dip at moderate or very low angles, and show very little sign of disturbance. Almost horizontal beds may be observed resting on the denuded edges of closely compressed synclines of Dharwar strata, showing that a period of denudation intervened between the Huronian upheaval and the deposition of the Kadapahs. Nevertheless, along the Eastern Ghâts, along the eastern edge of the Chhatisgarh basin, and south of the Son River, the Kadapahs themselves are intensely compressed and folded in such a manner as to indicate that they have evidently formed part of mountain ranges, giving undoubted evidence that in addition to the older period of mountain formation, another set of orogenic phemena has affected the peninsula after the Kadapah period.

There is reason to believe that this orogenic upheaval corresponds with the one that affected other parts of the world during the Silurian. The newest

age that could be assigned, therefore, to certain parts of the Upper Kadapahs, would be Silurian or Cambrian. The bulk of the formation, and certainly the totality of the Lower Kadapah belongs to the stratigraphical group known in other countries as Pre-Cambrian or Algonkian.

THE VINDHYAN SYSTEM.

THE Vindhyan System named after the Central Indian highland that extends north of the Narbada, Son, and Damuda, and south of the Jumna and Ganges, is a vast formation presenting two principal facies, one mainly characterized by limestones and calcareous shales, the other by enormously massive sandstones. As a rule, the Vindhyan strata dip at low or very low angles, and are even less disturbed than the Kadapahs. Yet, along the south-eastern border of the Aravalli range, and in those places where the Kadapahs themselves have been conspicuously disturbed, the Vindhyans have also been affected by folding and overthrust, indicating that they too have shared in the mountain-forming disturbance. Even in such localities they are not affected to the same degree as the Kadapahs, and it is evident that the main phase in the disturbance of the Kadapah had been completed before the deposition of the Vindhyans, and that the Kadapahs had been greatly denuded in the interval.

It is not quite certain, however, whether the disturbance of the Vindhyans is to be interpreted as an entirely independent system of orogenic disturbance, or merely as the final phase of the disturbance of the Kadapah. On the latter supposition, the disturbance might be of Silurian age, and the Vindhyans might consequently belong to the Cambrian or Silurian system. But if the disturbance of the Vindhyans belongs to a period really distinct from that of the disturbance of the Kadapahs, it probably belongs to the next great episode in the orogenic history of the globe, the great period of mountain formation of the Middle Carboniferous. If this be so, the Vindhyans are probably Upper Silurian or Devonian, and in this connection, it is worth noticing that the oldest rocks that can be proved to be certainly newer than Vindhyans are

Upper Carboniferous. Owing to the failure to discover any fossils, the question has to be left undecided, and it remains the main stumbling block in the correlation of Indian geology.

In their type-area, which covers an immense territory from Dehri-on-Son to Hoshangabad and to Gwalior, and from there to Agra and to Neemuch, the Vindhyans consist of four main divisions : a lower division exhibiting the calcareous facies which is known as the Lower Vindhyans ; an overlying division consisting of two enormously massive sandstones known under the names of Kaimur and Rewa, separated by some subordinate shales ; another division mainly calcareous and similar to the Lower Vindhyans which is known as the lower Bhanders, and lastly, an uppermost division of massive sandstones known as the Upper Bhander. The calcareous divisions average some 1,500 feet in thickness each, the sandstone ones about 500.

A remarkable group of highly siliceous volcanic rocks varying from rhyolites to quartz-andesites occurs in the Lower Vindhyans. Some of the limestones both in the Lower Vindhyans and in the Lower Bhanders exhibit a curious concretionary structure of spherules one to three centimetres in diameter consisting of variously coloured concentric shells in a matrix of a different colour. When the tints are vivid as in the case of the Sabalgarh stone near Gwalior, a strikingly beautiful material is produced which deserves to be more widely known. It has been largely used in the inlaid decoration of the buildings at Agra. Amidst the pebbles of certain Vindhyan conglomerates in Bundelkhand and in Southern India, there occur diamonds (the Panna and the Golconda diamonds) probably derived from the denudation of the basic volcanic dykes of Bijawar age.

There are several other outcrops besides that of the type-area of Central India, though none of them are so

extensive. It is only in the type-area that the Bhanders are represented. The Lower Vindhyans together with the Kaimur-Rewa sandstones are well represented in the Dhar forests north of the Narbada, and in Western Rajputana, the latter exposure exhibiting a particularly fine development of the volcanic beds of the Lower Vindhyans, locally known as the Malani beds from the State of that name. All the other Vindhyan outcrops consist mostly or entirely of Lower Vindhyans. They occupy the greatest part of the Chhatisgarh basin, and constitute the "Karnul Series" of the district of that name and of the Bhima Valley. The Sullavai sandstones of the Godavari Valley perhaps belong also to the same formation, unless they represent the sandstones and shale formation known collectively as the Red Shale Series in Rewa, where it underlies the Lower Vindhyans, and yet seems newer than any of the Kadapahs. It might be regarded as an oldest member of the Vindhyan system. Amongst the mountains of Northern India, the Vindhyans are represented by the Deoban Series near Chakrata, the Krol Series of the Simla area, the Attock Series of the Punjab.

Building-materials.

The Vindhyan limestones constitute a valuable source of lime, while the sandstones have yielded the material for the masterpieces of Indian art from the time of Asoka to the present day. Amongst the buildings of Vindhyan sandstone may be mentioned the Buddhist stupas of Barhut, Sánchi, and Sarnáth, the exquisite temples of Kajraha, the palaces of Gwalior, Delhi, Agra, Fatehpur-Sikri, Amber, Dig, the magnificent Jumma Masjids of Delhi, Agra, and Lahore. According to which beds are selected, it is possible to obtain monoliths of Egyptian magnitude, or flags of the thinness of slates. Such a variety of excellent material is obtainable that, in certain parts of India, public buildings and private dwellings, from the flooring to the walls and to the

rafters and ceilings are built entirely of stone. Large quantities of railing posts are manufactured out of Vindhyan sandstone, and, until a few years ago, it was the usual material for telegraph posts.

FOSSILIFEROUS REPRESENTATIVES OF THE CAMBRIAN AND SILURIAN SYSTEMS.

THROUGHOUT the rock systems that remain to be mentioned, the presence of fossils removes the element of doubt that affects the attempts at correlating the rocks hitherto dealt with. The outcrops that can be unhesitatingly referred to the oldest fossiliferous formations of the globe, the Cambrian and Silurian, are relatively of small extent when compared with the vast areas occupied by the formations hitherto mentioned. The oldest of all, the Cambrian, has hitherto been met with only in two localities, the Salt Range of the Punjab, and Spiti. The system is well developed in the eastern portion of the Salt Range, where its principal members are a purple sandstone, an arenaceous dolomite, and a group of bright-coloured shales with casts of salt crystals. The lower member, the Purple Sandstone, and the uppermost shales are quite unfossiliferous, but numerous fossils have been found in a band of shales intervening between the Purple Sandstone and the arenaceous dolomite. The fossils are of Middle Cambrian age, and include representatives of the most characteristic of the Palæozoic fossils, the curious crustacea known as trilobites. They were discovered by Dr. Warth in the year 1888. They belong to the genus *Redlichia* which characterizes the Lower and Middle Cambrian. The unfossiliferous Purple Sandstone is not unlike the Vindhyans. In the sections of the Eastern Salt Range, it is seen resting on a great mass of unstratified clay, in the midst of which are situated the layers of salt from which the mountain range derives its name. But the structure of the range is one of extensive overthrust faulting, and it is probable that

Cambrian of the Salt Range.

the Salt Marl is not in its normal situation with reference to the Cambrian strata, but is really much newer, and Tertiary in age.

Cambrian of Spiti.

Upper Cambrian fossils were discovered by Mr. Hayden in the upper portion of the Haimanta System of Spiti during the year 1898. These fossiliferous beds, whose aggregate thickness is about 1,000 feet, consist of slates with some quartzites and dolomites. They overlie with apparent conformity some 3,000 or 4,000 feet of unfossiliferous strata recalling the Upper Kadapah, and consisting of slates, some of which are ferruginous and carbonaceous, and of quartzites. These unfossiliferous beds may perhaps represent the Middle and Lower Cambrian. Amongst the fossils discovered by Mr. Hayden, there are trilobites belonging to the genera *Ptychoparia, Dikelocephalus* and *Olenus*.

Silurian of Spiti.

The Silurian is not developed in the Salt Range, where the Cambrian is immediately succeeded by Upper Carboniferous beds. In Spiti, the Upper Cambrian is unconformably succeeded by an unfossiliferous quartzite, about 1,500 feet thick, succeeded by highly fossiliferous limestones and calcareous shales of a total thickness of some 500 or 600 feet. Amongst the leading fossils are a number of trilobites belonging to the genera *Cheirurus, Illœnus, Asaphus, Calymene*, and numerous corals, cystoids, brachiopods and gastropods. The fossiliferous beds include both Lower and Upper Silurian horizons (Caradoc to Wenlock).

Silurian of Burma.

In the Northern Shan States of Burma the Lower Silurian is represented by shales of various colours with thick bands of limestones, containing numerous cystideans, bryozoa, brachiopods and trilobites belonging to the genera *Remnopleurides, Calymene, Pliomera, Sphærocoryphe;* and the Upper Silurian consists of strata exhibiting two different

facies : an arenaceous facies (Namhsim Sandstone) containing numerous brachiopods, and some trilobites of the genera *Illænus*, *Encrinurus*, *Calymene*, *Cheirurus*, *Phacops* (*Dalmanites*); and a calcareous facies (Zebingyi Beds), with graptolites, brachiopods, cephalopods, and trilobites of the genera *Phacops* and *Dalmanites*. The Namhsim Sandstones are principally of Wenlock age, the Zebingyi Beds slightly newer.

Between the Lower Silurian and the Huronian or Archæan of the Shan States, there intervenes a thick series of quartzites and slaty shales that have been regarded as Cambrian, but containing no fossils.

DEVONIAN AND LOWER CARBONIFEROUS SYSTEMS.

THE strata intervening between the Silurian and the unconformity-conglomerate which, almost everywhere in India as also in many other parts of the world, indicates the commencement of the Upper Carboniferous, that is, therefore, the Devonian and Lower Carboniferous, are even more scantily represented in India than the Cambrian and Silurian. The scantiness of outcrops of those particular horizons is a characteristic feature of the region included within the limits of the Indian Empire. These horizons are entirely absent from the Peninsular region, unless it be shown eventually that the Vindhyans are partly of that age. Fossils of undoubted Devonian age have only been found in Chitral and in the Northern Shan States, but in neither case has their stratigraphy been completely worked out. The presence of the trilobite *Phacops latifrons* and of the curious coral *Calceola sandalina* amongst the fossils of the Northern Shan States indicates that the Middle Devonian horizon is represented.

Devonian of Chitral and of Burma.

In the Spiti region of the Himalaya, the Muth Quartzite, an unfossiliferous band some 500 feet thick, and a group of limestones between 300 and 400 feet in thickness with poorly preserved fossils, overlying the Muth Quartzite, may possibly represent the whole or a part of the Devonian. These beds are succeeded by the only undoubted Lower Carboniferous strata that have yet been observed in the Indian Empire.

Lower Carboniferous of Spiti.

Owing to the great unconformity at the base of the Upper Carboniferous, the outcrop of this formation is discontinuous even in the Spiti region. In some

parts of Spiti the conglomerate situated at the base of the Upper Carboniferous rests directly on fossiliferous Silurian beds, the Muth Quartzite itself having been removed by denudation, but elsewhere the Muth Quartzite and the possibly Devonian limestones that accompany it have been preserved, and there may intervene between them and the Upper Carboniferous conglomerate a variable thickness of strata which include undoubted representatives of the Lower Carboniferous.

In the region adjoining the lower part of the Spiti Valley, the aggregate thickness of the strata extending from the presumed Devonian to the Upper Carboniferous amounts to over 4,000 feet. In this particular case, there seems to be a gradual passage upwards into the conglomerate, and it seems that the usual unconformity is locally bridged over, the whole of the Carboniferous System being present in this particular section. Where the maximum thickness is exhibited, the Carboniferous beds underlying the conglomerate have been divided into two sections, each of which is about 2,000 feet thick. The lower division named the Lipak Series is mainly calcareous and shaly, and contains numerous fossil brachiopods, amongst which may be mentioned several species of *Productus*, and the typically Lower Carboniferous *Syringothyris cuspidata*, numerous mollusca, and trilobites of the genus *Phillipsia*. The upper division known as the Po Series consists of quartzites and shales. It contains two sub-divisions, a lower one with a few fossil plants that seem identical with certain plants of the Culm of Europe and Australia (Lower Carboniferous), and an upper sub-division with marine fossils, amongst which one notices numerous Bryozoa. These beds have been named the "Fenstella shales" from the leading genus of Bryozoa. They are closely connected with the overlying conglomerate, and belong probably to the Upper Carboniferous.

In the district of Rupshu, in the neighbourhood

of Spiti, the Lower Carboniferous appears to be represented, but the beds have been much altered by compression and by the contact effects of granitic intrusions, so that the fossils are to a great extent obliterated.

In Kashmir there is an extensive volcanic formation, which is probably Lower Carboniferous in age.

GEOLOGICAL HISTORY OF INDIA DURING THE UPPER CARBONIFEROUS, PERMIAN AND MESOZOIC PERIODS.

Orogenic phenomena in Carboniferous times.

TOWARDS the end of the Middle Carboniferous, there occurred an extensive orogenic upheaval in many parts of the globe. Mountains, which denudation has now removed, were upheaved to an altitude comparable with that of the highest ranges of the present day, and there are even indications of the existence of glaciers. Except where sedimentation continued uninterrupted in places that remained unaffected by these movements of the earth's crust, we find, therefore, a well marked stratigraphical break at the base of the Upper Carboniferous, which usually rests unconformably on the underlying rocks. The junction is usually indicated by an unconformity-conglomerate, which often exhibits peculiar characters that have been regarded as glacial. This break is particularly conspicuous in India where the Lower Carboniferous is unknown except in the very local Himalayan exposures just mentioned. With this exception the Carboniferous Systems, almost everywhere in India, commences with a peculiar boulder bed which cannot be older than Middle Carboniferous, and which supports a vast series of Upper Carboniferous and Permian strata.

So pronounced is this break that Indian geologists came to the conclusion that it would be more natural to place the dividing line between the primary and secondary eras at the base of this boulder bed, that is at a horizon corresponding with the Middle Carboniferous of British nomenclature, rather than between the Permian and Trias, as has been done in Europe. It was even thought that this distribution of the stratified series in India implied that the geological history of the Indian area was quite unrelated to that

of Europe, and should, to a great extent, be treated independently. The correct interpretation of this attitude on the part of Indian geologists, is that the break is somewhat more conspicuous in India than in Europe. The Carboniferous system in Europe was originally established in order to include all the Palæozoic coal measures of that country. But it has been found on closer study, that in Europe, as in India, there is a break just as pronounced and quite as general between the Middle and Upper Carboniferous, and that it is situated at the same horizon. There might be some justice in proposing that the international geological nomenclature be altered accordingly, and the Secondary or Mesozoic era made to commence with the Uralian or Stephanian stage, that is, the Upper Carboniferous, but such attempts at reforming the geological nomenclature, although theoretically sound, are, in practice, futile. There is no more necessity to alter the established nomenclature at each fresh geological discovery than there would be to alter the standard metre or kilogramme at each fresh measurement of the earth's meridian.

After the great upheaval of the Middle Carboniferous, the crust of the globe remains comparatively quiescent until the middle of the Tertiary era. Throughout the intervening periods we cannot, therefore, avail ourselves of any marked stratigraphical unconformities to establish divisions through that long series of ages. There are, however, indications of certain universal or widespread alterations in the relative level of the ocean that have left their mark in the stratified record, and that greatly assist in demarcating lines of division. Whenever the level of the ocean was comparatively high, its sediments invaded certain areas that had previously been continental. This was particularly the case at the time of the Upper Cretaceous (the period of the Chalk).

unusually low level, the previously formed sediments were left dry, and sedimentation was interrupted above them until the next return of the ocean. Owing to the wide areas over which they can be recognized, it is these interruptions which have principally been made use of as lines of demarcation between the various systems. Some of the most conspicuous of these interruptions, for instance, the one between Permian and Trias that separates the Primary from the Secondary, or the one between the Cretaceous and Eocene that separates the Secondary from the Tertiary, are as distinct in India as in Europe. It must be noticed, however, that owing to the quiescence of the earth's crust during these periods, the breaks are unaccompanied by any stratigraphical unconformity. Consequently they easily escape notice, and it has hitherto been the custom to admit that in contradistinction to what is observed in Europe, there is in India a gradual passage from Primary to Secondary, and from Secondary to Tertiary. A closer study of the fossil contents of the rocks has now revealed the universal presence of the stratigraphical breaks, at least amongst the marine strata, and their coincidence with those originally established in Europe. The occurrence of ferruginous beds representing a peculiar alteration product of rocks exposed to the air, known as "laterite," often assists in locating these stratigraphical breaks in the absence of a stratigraphical unconformity. These ferruginous layers represent the altered surface of the sediment which was exposed to atmospheric agencies during the interval between two marine invasions.

Stratigraphical breaks indicated by lateritic bands.

The corrugation of the earth's crust that produced the great upheaval of mountain ridges in Middle Carboniferous times also accentuated a deep furrow almost encircling the world, and constituting an

Northern and southern continents separated by the Tethys.

ocean, of which the present Mediterranean is the last remnant. This extinct ocean, known in geological nomenclature as the Tethys, completely separated the continents of the Northern and Southern hemispheres, when it thus became deepened in Upper Carboniferous times. During the Lower and Middle Carboniferous, the separation was not so complete, and the lands of both hemispheres supported similar plants and animals. But during the Upper Carboniferous and Permian, all connection was severed, and the southern continent including the Indian Peninsula, parts of South America and South Africa, and Australia, joined together by lands that have now subsided beneath the Atlantic and Indian Oceans, was inhabited by a flora and fauna quite different from that of the northern lands. Something of the same sort is observed at the present day in Australia and New Zealand which, being separated from the rest of the World by a broad expanse of Ocean, are tenanted by different plants and animals. Marine strata of Upper Carboniferous to Eocene age, largely consisting of shales and limestones are developed on an enormous scale in many parts of the extra-peninsular regions of the Indian Empire, and can readily be correlated with those of other parts of the world by means of their abundant fossils. The extra-peninsular regions were then submerged beneath the Tethys, while the Peninsula remained as today a continental area. Consequently the marine beds of the extra-peninsular region are represented in the Peninsula by great masses of fluviatile sandstones associated with coal-seams and containing no other fossils but fragmentary remains of plants and terrestrial animals. Owing to the differences between them and the corresponding flora and fauna of more northern lands, and owing to the scarcity of sections combining the marine and fluviatile facies, and in consequence also of the unfossiliferous nature of many of the fluviatile sandstones, it has not yet been possible

to correlate exactly all the peninsular sandstones with the corresponding marine strata of the extra-peninsular regions. In the following pages it will be convenient, therefore, to mention separately the great sandstone formations of the peninsula and the calcareous and shaly marine beds of the extra-peninsular regions. The name of Gondwana series, originally applied to these fluviatile formations in India, has been extended to beds containing a similar fossil flora in South America, South Africa, and Australia; the southern continent of which these lands are the remnants is spoken of as Gondwana-Land. For the Palæozoic (Primary) formations that still remain to be noticed, and for the succeeding Mesozoic (Secondary) ones, it will, therefore, be necessary to examine separately two facies: the Gondwana facies with terrestrial fossils, and the marine facies.

Gondwana-Land.

UPPER CARBONIFEROUS AND PERMIAN SYSTEMS.

(*a*) *Gondwana facies.*

THE Gondwana series consists principally of sandstones of fluviatile origin with some subordinate shales and ironstones, the latter probably of lateritic nature. Certain horizons are rich in coal-seams. These strata occupy basins bounded by faults in the midst of the older rocks of the Indian Peninsula. These basins are arranged in linear series along the valleys of the Damúda and Barákar, the Mahánadi and the Godávari rivers. The Damúda and Mahánadi series of exposures converge in a westerly direction and coalesce in southern Baghelkhand from where they continue westwards on the southern side of the Narbada valley, concealed at times by the basaltic lavas of the Deccan Trap until they culminate in the lofty peaks of the Satpura Range. The Rajmahal hills of Bengal also include Gondwana rocks. In the Himálayan region, typical Gondwanas are found in the neighbourhood of Darjiling and in Bhotán.

The Gondwana rocks are divided into two principal groups, the Lower Gondwanas of Palæozoic age, and the Upper Gondwanas of Mesozoic age. The Lower Gondwanas themselves have been divided into three principal series, known under the names of Talchir, Damúda and Panchet.

Talchir boulder-beds.

The base of the Talchir, whenever it is not removed out of view by faulting, is characterized by a peculiar boulder-bed regarded as glacial on account of its silt-like matrix and of the striations observed on some of the pebbles. It is known as the Talchir conglomerate from the name

of a coal-field in the Mahánadi region. The upper beds of the Talchir constituting the Karharbari division contain some valuable coal-seams. The leading fossils of the Talchirs are impressions of detached leaves known as *Gangamopteris* which differ by the absence of a midrib from the leaves of *Glossopteris* characterizing the overlying Damúda beds.

The Damúda beds are the chief coal measures of India. The lower portion known as the Barákar division is the one most widely spread, and containing the most valuable coal-seams. The upper coal-bearing horizon is known in Bengal as the Raniganj division.

The uppermost division of the Lower Gondwanas, the Panchet, is destitute of coal. It contains fossil remains of plants, some of which are identical with those of the underlying Damúdas, and remains of extinct reptiles and amphibians.

The geological horizon of the Talchir conglomerate corresponds approximately with the base of the Upper Carboniferous (Uralian or Stephanian); at any rate, these beds are not older than Middle Carboniferous (Moscovian). The Karharbari coal-seams belong to the base of the Upper Carboniferous. The Barákar coals belong to a higher horizon of the Upper Carboniferous. The Raniganj coals may be Lower Permian (Permo-Carboniferous or Artinskian). The Panchet probably corresponds with the Upper or true Permian or Zechstein.

It will be seen, therefore, that the age of the coal measures of India differs considerably from that of the coal measures of Great Britain and the Franco-Belgian basin, all of which are Lower or Middle Carboniferous in age. The Lower Gondwana coal corresponds with the Upper Productive coal measures of North America, and with the coal measures of central France, which recall the Damúdas on account of the enormous thickness of some of their seams.

The constitution of the Lower Gondwanas, where most typically developed in Bengal, may be tabulated as follows :—

		Approximate age.
PANCHET		ZECHSTEIN.
DAMUDA	RANIGANJ IRONSTONE SHALES BARAKAR	ARTINSKIAN.
TALCHIR	KARHARBARI	URALIAN.
	BOULDER-BEDS	MOSCOVIAN.

In the coal-fields situated outside of Bengal, some of these divisions have received different names. Detailed monographs of all the coal-fields have been published in the Memoirs and Records of the Geological Survey of India.*

* Most of these monographs are out of print. They can be consulted, however, in most public libraries.

UPPER CARBONIFEROUS AND PERMIAN.

(*b*) *Marine facies.*

Productus-beds.

THE marine representatives of the Ural and Artinsk stages are very widely developed throughout the extra-peninsular regions of the Indian Empire, where they are usually known as the Productus-beds, from the great abundance of fossil brachiopods belonging to that genus which they contain. It is in the Salt-Range that these beds have been most completely studied. In that range they are mostly calcareous and are collectively known as the Productus Limestones. They have been classified as Lower, Middle and Upper Productus limestones, each of which is further sub-divided. The base of the Lower Productus limestones is a boulder-bed apparently glacial, identical with the Talchir boulder-bed and of the same age. It contains a variety of fossils and most of the overlying beds are highly fossiliferous. The successive faunas have been studied in great detail by Waagen, whose descriptions have been published in the Palæontologia Indica. The fauna of the Lower Productus limestone and that of the lower divisions of the Middle Productus limestones indicates that these beds belong to the Upper Carboniferous Period. The remainder of the Productus limestones, owing to the presence of fossil ammonites with complex sutures, such as the genera *Cyclolobus* and *Medlicottia*, is correlated with the Lower Permian (Permo-Carboniferous or Artinskian). The uppermost beds of the Upper Productus limestones are immediately succeeded by a conglomerate of Triassic age, the representatives of the Zechstein or Upper Permian being absent from that region as from all the exposures of marine Permian in India.

Boulder-bed of the Salt-Range.

The same rocks, either calcareous or shaly, are extensively developed all along the central ranges of the Himalaya. (The outer ranges are largely occupied by rocks corresponding with the ancient unfossiliferous series of the Peninsula). The most constant member of the group is the one known as the Productus shales which corresponds with the Upper Productus limestones of the Salt-Range, and is of Lower Permian age.

In Garhwal, the Productus shales overlie unconformably beds of Lower Palæozoic age. In Spiti, they pass inferiorly into a calcareous sandstone of Upper Carboniferous age, the base of which is conglomeratic.

Permian and Upper Carboniferous of Spiti.

This conglomerate usually rests unconformably on various horizons ranging from Silurian to Lower Carboniferous, except where the Po Series, mentioned in a previous paragraph, attains its maximum development: there the conglomerate passes conformably downwards into the uppermost member of the Po Series, the Fenestella shales, themselves of Upper Carboniferous age.

It is important to notice, therefore, that the Spiti conglomerate is not the equivalent of the Talchir conglomerate or the boulder-bed of the Salt-Range, but belongs to a higher horizon corresponding probably with some zone of the Barákar.

The Fenestella shales themselves appear to correspond with some of the Barákar and Karharbari horizons, and are represented in Kashmir by the Zewan beds which underlie the Productus Shales (Lower Permian), and overlie shales and sandstones containing fossil fishes and impressions of *Gangamopteris* which belong to one of the zones of the Talchir and rest on volcanic rocks, probably of Lower Carboniferous age.

Zewan beds of Kashmir.

Beds corresponding with the Productus limestones of the Salt-Range are known in the Eastern Himalaya. In Burma and in Tenasserim, they are largely repre-

sented by limestones crowded with foraminifera of the genera *Fusulina* and *Schwagerina*. The Fusulina limestones have also been observed in Balúchistán in the Pishin and Zhob districts. The respective limits of Upper Carboniferous and Lower Permian in all these exposures has not yet been ascertained. One of the curious "exotic blocks" of Johar on the Tibetan frontier, scattered through a gigantic volcanic breccia of Cretaceous age, that forming the peak known as Chitichun I, is a huge mass of limestone containing fossils of the same age as the Kalabagh zone of the Salt-Range at the base of the Lower Permian.

Fusulina and Schwagerina limestones.

Chitichun I.

The uppermost beds of the Lower Permian of Garhwal contain the remarkable genus of ammonites, discovered in 1879 by Mr. Griesbach and described by him as *Otoceras*. The layer containing this fossil is immediately succeeded by Lower Triassic beds without any indication of unconformity, and was, therefore, taken to represent a passage zone between the Permian and Trias. But there is a complete change of fauna between this layer and the succeeding beds indicating a break quite as pronounced as in the Salt-Range. The Otoceras layer is ferruginous which indicates that it probably remained exposed to the atmosphere, and that there was an interruption of sedimentation after the period during which it was formed. The newest age that can be assigned to it is the top of the Lower Permian.

Otoceras beds.

It follows from these observations that the marine equivalents of the Zechstein of Central Europe, of the Magnesian Limestone of England, and of the typical Permian of Russia are unknown in India. Far from there being a gradual passage from Permian to Trias, the gap between Palæozoic and Mesozoic is even broader

Absence of marine equivalents of Zechstein.

amongst the marine strata of India than amongst those of Europe, in spite of deceptive appearances of continuity. The marine representatives of the Permian in India are restricted to the Lower Permian or Artinsk stage which many geologists distinguish under the name of Permo-Carboniferous regarding these strata as passage beds between Carboniferous and Permian.

TRIASSIC, JURASSIC, AND LOWER CRETACEOUS SYSTEMS.

(*a*) *Gondwana facies.*

THE Upper Gondwanas are for the greatest part barren of useful minerals and have, therefore, received very little attention from the Geological Survey of India. Their age is often doubtful and their nomenclature confused.

The unfossiliferous red sandstones of the Mahadeva group which attain a thickness of some 8,000 feet in the Mahadeva hills of the Satpura Range, are perhaps of Triassic age. Similar beds, perhaps of the same age, overlie the coal measures in South Rewa and in some of the Damúda and Mahánadi valleys series of coal-fields.

The Dubrajpur sandstone of the Rajmahal hills is perhaps also their equivalent. It is worth noticing that there is a remarkable parallelism between the Gondwanas of the Indian Peninsula and the New Red Sandstone of England which also includes beds of Upper Carboniferous, Permian and Triassic age so closely connected that many geologists have insisted upon including them in one continuous system.

The remaining divisions of the Upper Gondwana are usually of small thickness and are closely related to one another. Their age ranging from Upper Jurassic to Lower Cretaceous is sometimes approximately and sometimes accurately defined by means of their fossil contents. In ascending order there are four divisions: firstly, the Rajmahal; secondly, an intermediate group for which no general name has yet been selected; thirdly, the Jabalpur; and fourthly, the Umia. The three first and sometimes the last are represented all along the East

Coast of the Peninsula from the neighbourhood of Vizagapatam to that of Tanjore.

The type of the Rajmahal division is observed in the hills of that name in Bengal where the fossil plant-bearing beds are associated with basaltic rocks. Basic dykes connected with this volcanic outburst are common in some of the coal-fields of Bengal and include some interesting petrological types, such as the mica-peridotites discovered in 1894 by Mr. T. H. Holland.

Mica-peridotites.

The Denwa beds of the Satpura range and the Kota-Maleri beds of the Godavari valley, and perhaps the Atgarh sandstones of Cuttack appear to belong approximately to the same horizon as the Rajmahal. Some fine-grained buff-coloured sandstones from the Atgarh outcrop have yielded the material of which are built the world-famed temples of Bhuvaneshvar and "black pagoda" of Konarak, and the temple of Jagannath at Puri.

The type of the Jabalpur beds is near the town of that name. Instead of consisting chiefly of sandstones like the groups hitherto mentioned, they are largely made up of clays and contain beds of lignite.

In Kachh the Umia beds, chiefly sandstones and shales, attain a vast thickness (3,000 feet), and contain strata with fossil plants closely related to the Jabalpur flora, intercalated between beds with marine fossils respectively of Wealden and Lower Greensand age. This fixes the age of the newest Gondwanas as Lower Cretaceous. Beds apparently of the same age in Kathiawar and Gujrat contain seams of lignite.

TRIASSIC, JURASSIC AND LOWER CRETACEOUS SYSTEMS.

(*b*) *Marine facies.*

THE marine representatives of the Trias and Jura are enormously developed in the extra-peninsular regions of the Indian Empire, the Upper Jurassic being also well developed along the borders of the peninsular area in Kachh and Rajputana. The different beds of the marine Mesozoic formations in India can be readily correlated with their equivalents in other parts of the world by means of the numerous fossil ammonites which they contain. Each horizon of the Mesozoic is characterized by a particular species of ammonite, and the zones thus defined can be recognized in all parts of the world. It is in the Mesozoic zones of the Central Himalaya and the North-Western Frontier, that a number of able scientists, amongst whom special mention should be made of Stoliczka, Griesbach, Middlemiss, Diener, and von Krafft, and Hayden, have accomplished the most brilliant geological work as yet achieved in India.

The Trias consisting principally of limestones, calcareous shales and massive dolomites is characterized in the Salt-range and the Central Himalaya by a richness in fossils unequalled in any other part of the world. These fossil organisms, many of which are strikingly beautiful, have been described in a series of magnificent monographs by Waagen, Mojsisovics, Diener and Bittner.

The Trias, as its name implies, includes three principal divisions, a lower one characterized principally by the ammonite genus *Tirolites*, a middle one which is the zone of maximum development of the *Ceratites*, and an upper one characterized chiefly by

Trachyceras. These three stages correspond respectively with the classical divisions of Bunter, Muschelkalk and Keuper.

Trias of the Himalaya.

It is especially in the Central Himalaya that the system is most complete, the Upper Trias, in particular, being developed on a truly gigantic scale. In Spiti, for instance, the respective thicknesses of the three divisions are roughly 50, 500 and 3,000 feet.

The lower division corresponds with the "ceratite-beds" of the Salt-range which are separated by a conglomerate from the underlying Permo-Carboniferous. In the Himalaya there is no apparent break, but, as already explained, it is probable that there was an interruption of the sedimentation after the deposition of the *Otoceras* zone.

Amongst the fossils characterizing various horizons of the Lower Trias, may be mentioned, *Ceratites normalis*, the genera *Danubites*, *Tirolites*, and *Meekoceras*, and, in the upper zones, *Rhynchonella Griesbachi*.

A number of zones characterized by peculiar species follow one another in the same order both in the Himalaya and in the Salt-range, and they are identical with similar zones observed in Europe.

The Middle Trias is characterized by the great abundance of the species belonging to the genera *Ceratites* and *Ptychites*, by *Spiriferina Stracheyi* in the lower beds, and, in the upper beds, by *Daonella Lommeli*.

Amongst the enormous succession of strata constituting the Upper Trias may be noticed, towards the base, the beds with *Halobia*, higher up those known as Tropites beds from the abundance of ammonites belonging to that genus, still higher the Juvavites beds of Spiti and Halorites beds of Kumaon containing innumerable ammonites, amongst which the remarkable genus *Pinacoceras*, lastly the *Monotis salinaria* shales,

and strata with *Spiriferina Griesbachi* and *Megalodon*. The Monotis shales are also largely developed in the Pishin and Zhob districts of Baluchistan, while shales and limestones with *Halobia* constitute a considerable proportion of the Arakan Yoma.

The great thickness of Jurassic limestones, which overlies the Trias in the Central Himalaya, has yielded very few fossils, and therefore cannot be readily subdivided into zones. The limestones are overlaid by the "Spiti shales" of uppermost Jurassic age, whose well-known ammonites are current as an article of trade, being used all over India for certain religious rites.

Jurassic of Baluchistan.

In Baluchistan, the Lias (Lower Jurassic) consists of 3,000 or 4,000 feet of black limestones, some of them oolitic, and calcareous shales, with some highly fossiliferous bands, in which the principal subdivisions of the European series have been identified. They are succeeded by an equal thickness of massive limestones of Middle Jurassic age, which constitute the lofty peaks that surround Quetta. This massive limestone is unconformably overlaid by the Lower Cretaceous, the Supra-Jurassic series being absent from Baluchistan.

Jurassic of Kachh.

The Upper Jurassic zones, missing in Baluchistan, are represented in Kachh by a thickness of about 3,000 feet of colitic limestones and shales, passing upwards into sandstones; all the principal ammonite-zones of the Upper Jurassic of Europe have been identified in this sequence. The same horizons are represented in the Salt-range and in Western Rajputana. The Jurassic is largely represented in Burma, where, however, it has not been studied in detail.

Lower Cretaceous.

The Upper Jurassic of Kachh is succeeded by an equal thickness of Lower Cretaceous sandstones, often glauconitic, extending up to the horizon of the Lower Greensand,

and constituting the Umia beds, already mentioned with reference to the Gondwana facies.

In Baluchistan, the Lower Cretaceous is represented by the black "belemnite shales," containing belemnites of the genus *Duvalia*, and by the overlying brilliantly striped white and red limestones known as the "Parh limestones." The Himalayan equivalent of these rocks is the Giumal sandstones. The equivalents of the Parh limestones have been observed in the Arakan Yoma and the Andaman Islands.

THE UPPER CRETACEOUS SYSTEM.

Absence of Middle Cretaceous.

THE middle stages of the Cretaceous, especially those just preceding the Gault, are not known in India, this horizon coinciding with one of the most pronounced breaks in the Indian Geological sequence.

Upper Cretaceous of Southern India.

It is near the East Coast of Southern India, from Pondicherri to Trichinopoli, that the most complete sequence of Upper Cretaceous beds is observed. The beds are principally shales and sandstones with some calcareous bands full of well preserved fossils that have been described in great detail by Forbes, Stoliczka and Kossmat. There are three principal divisions, the Utatur, Trichinopoli and Ariyalur. The Utatur, mostly shales with some coral limestones, contains over 100 species of ammonites distributed in three zones: the Schloenbachia beds with *Schloenbachia inflata, Turrillites Bergeri, Hamites armatus;* the Acanthoceras beds with numerous species of *Acanthoceras;* and with *Turrilites costatus;* and an upper zone with *Acanthoceras conciliatum, and Nautilus Huxleyanus.* These three divisions correspond respectively with the Gault, Cenomanian, and Turonian.

The Trichinopoli beds of Lower Senonian age (with 27 species of ammonites), consisting of sands, clays and shingle beds intercalated with shell-limestones, largely used for ornamental purposes, include a lower division characterized by *Pachydiscus peramplus, Protocardium Hillanum,* etc., and an upper division with *Placenticeras Tamulicum, Hiteroceras indicum,* etc.

The Ariyalur, mostly Upper Senonian, is chiefly arenaceous, and contains at its base a highly fossiliferous

band with more than 50 species of ammonites belonging to the genera *Pachydiscus*, *Baculites*, *Sphenodiscus*, *Desmoceras*, etc., and numerous lamellibranchiata and gastropods amongst which the Cypreidæ and Volutidæ are particularly well represented. The uppermost strata of the Ariyalur are known as the Niniyur beds, and contain the characteristic Danian species *Nautilus Danicus*.

Upper Cretaceous of Baluchistan.

Cenomanian beds containing *Acanthoceras* are known in Hazara and in the Samana range. The Upper Cretaceous is largely developed in Baluchistan and in the Laki range of Sind, its lower members, the limestones constituting the Hemipneustes beds, of Campanian or Lower Maestrichtian age (Lower or Middle zone of the Aturian or Upper Senonian) containing echinoids of the genera *Hemipneustes*, *Pyrina*, *Clypeolampas*, *Noetlingia*, and ammonites belonging to *Pachydiscus* and other genera. They are succeeded by shaly beds usually unfossiliferous, but containing a band scarcely six inches thick, crowded with ammonites belonging to the genera Indoceras, Sphenodiscus, Pachydiscus, Schlüteria, Baculites. This is the newest ammonite zone yet observed in Northern India. The ammonite shales are followed by a great thickness of sandstones often interbedded with volcanic material, known as the Pab sandstones. Highly fossiliferous bands are sometimes associated with the Pab sandstones, especially in their upper zones, the commonest fossil being *Cardita Beaumonti*. It is possible that some of the uppermost *Cardita Beaumonti* beds are of Danian age.

Bagh and Lameta beds.

The great volcanic group of the Deccan Trap in the Peninsula is underlaid by a formation of slight thickness, but of considerable horizontal extent, constituting the Lameta series where it exhibits the

fluviatile facies, and the Bagh beds, where it is marine. The Bagh and Lameta correspond with the Utatur of Southern India. The Tharia beds of Assam are perhaps of the same age. The "Intertrappeans" of Rajamahendri correspond with the Pab sandstones of Baluchistan. The Himalayan representatives of the Upper Cretaceous are known as the Chikkim Series.

At a period intermediate between the *Hemipneustes* and the uppermost ammonite zones of Baluchistan, commenced the principal phase of the stupendous eruptions of the Deccan Trap, which continued up to the end of the Cretaceous, the uppermost layer of the *Cardita Beaumonti* beds in Sind being still overlaid by a basalt flow. These eruptions have covered an enormous portion of the Peninsula with basaltic flows, the western portion in particular, north of latitude 16° being entirely occupied by this formation. Rhyolitic lava flows and intrusive elæolite syenites belonging to this system have been discovered respectively by Mr. Fermor at Pawagarh hill in Gujrat, and by Dr. Evans at Girnar hill in Kathiawar.

Deccan Trap.

In Baluchistan the series consists largely of submarine tuffs, and contains numerous andesitic and rhyolitic as well as basaltic rocks. The rock often assumes the character of a breccia half intrusive, half extrusive, in which the included blocks of all kinds and ages of sedimentary and crystalline rocks vary from the size of a small pebble to that of an entire hill mass. Singular appearances are thus produced both in Baluchistan and in the Himalaya, the best known example of which is the great igneous mass containing the "exotic blocks" of Johar on the Tibetan frontier. The Deccan Trap is also well represented in the Upper Indus valley in Ladakh.

Exotic blocks of Johar.

In the Zhob Valley of Baluchistan, the series is represented by huge intrusions of gabbro associated with serpentines locally rich in chrome. Similar rock are extensively developed in the Arakan Yoma and the Andaman Islands.

Chrome-bearing serpentines.

The Deccan Trap eruptions appear to have coincided with the final breaking up of Gondwana-Land.

THE EOCENE SYSTEM.

If we represent on a map of India, the various geological divisions so far described, we shall find that one of the three regional divisions of India, the Peninsula has now been completed except for some strips of quaternary beds along the sea-coast and along the valleys of some of the great rivers, and a few Tertiary exposures in Gujrat, Kathiawar, and Western Rajputana. Of the remaining paragraphs of this notice, those concerned with the quaternary era will deal principally with the third of the great regional divisions, the Indo-Gangetic plain, while those concerned with Tertiary rocks will deal principally with the great mountain ranges of extra-peninsular India.

With the end of the Cretaceous, the Mesozoic or secondary era came to a close. The gap between Cretaceous and Tertiary, due to a universal temporary regression of the ocean, is just as pronounced in India as in any other part of the world. Even in Sind where the oldest Tertiary of India is met with, it does not contain any beds that can be referred to the Thanetian or lowest Tertiary, while the Cretaceous of that same province scarcely reaches the base of the Danian. Therefore both the uppermost Cretaceous and lowermost Tertiary are missing.

Stratigraphical break between Cretaceous and Tertiary.

The Eocene in India, as in other countries, includes the bulk of the nummulitic limestones. It includes three principal divisions: the Ranikot, the Laki, and the Khirthar. The Ranikot restricted to a comparatively small area in the province of Sind, includes a lower division of fluviatile sandstones corresponding with the Woolwich and Reading beds, and an upper marine

Ranikot Series.

division contemporaneous with the London Clay. The uppermost beds of the Upper Ranikot contain the earliest abundant nummulites belonging principally to the species *N. planulatus*.

Laki series with coal-seams.

The Laki division exhibits either a shaly arenaceous or a calcareous facies according to various localities. Its characteristic nummulites are *N. atacicus*, and *N.* (*Assilina*) *granulosa*. The Laki limestones abound also in foraminifera of the genus *Alveolina*. The Laki division is economically of great importance containing as it does an important coal-bearing horizon in Baluchistan and the Punjab.

Khirthar series.

The Khirthar consists largely of limestones which, in the range of that name along the Sind-Baluchistan frontier, are as much as 3,000 feet thick. It contains the zones richest in nummulites amongst which may be mentioned *N. laevigatus*, *N. perforatus*, *N. gizehensis*, *Assilina spira*.

The upper beds of the Khirthar limestone contain *N. complanatus*, the largest species of the genus. The Laki and Khirthar correspond with the Lutetian, that is, the Middle Eocene. The Bartonian (Upper Eocene) doubtfully present at the top of the Khirthar in the Mula Pass of Baluchistan is certainly absent from all other exposures, there being a widespread unconformity between the Khirthar and the following beds of Oligocene age.

Both the Laki and Khirthar are well developed in Kachh, and in the Salt-range in the Arakan Yoma and in the Andaman Islands. The Laki is largely developed in Western Rajputana. The nummulitics of Surat and of Assam and the Subathu group of the Simla region correspond with the Khirthar

THE PEGU OR MEKRAN (FLYSCH) SYSTEM.

(*Oligocene and Lower Miocene*).

THE end of the Eocene coincides with the opening of the last and most important chapter of the geological history of India. The quiescent conditions that had lasted ever since the Upper Carboniferous now came to an end, and the earth's crust entered into a renewed phase of disturbance. The enormous mass of sediments that had so quietly accumulated upon the gradually sinking floor of the Tethys was now powerfully compressed in a horizontal (tangential) direction, and was thrown into a succession of ridges, which became the great mountain ranges of the present day: the Alps, the Pyrenees, the Himalaya.

Three phases can be distinguished in this grand upheaval, one at the end of the Eocene, one in the Middle Miocene, and the last in the Middle or Upper Pliocene. The first upheaval, although it extensively folded the Eocene and underlying older strata, uplifting them in many regions into ranges of considerable altitude, was not nevertheless sufficient to obliterate the Tethys. This ocean still preserved its continuity; the gradual subsidence of its floor, of which we have evidence from Upper Carboniferous to Eocene, still continued or even became accentuated, judging by the enormous thickness of sandstones and gritty shales all bearing evidence of deposition in rather shallow water that accumulated throughout the Oligocene. These dark grey or greenish shales and often calcareous sandstones are singularly uniform and monotonous in appearance, constituting the bulk of the great formation known as the "flysch." Beds of similar appearance had already been deposited in the same area during Eocene and even

Upheaval of the Himalaya.

The flysch.

Cretaceous times, but it is during the Oligocene that most of the flysch was deposited.

Towards the end of the Middle Miocene, a second orogenic phase still more powerful than the Upper Eocene one upheaved the flysch strata, folding them into innumerable corrugations, and the Tethys was cut up into a series of disconnected lagoons or inland seas which finally disappeared in the last great upheaval of Pliocene times.

A homogeneous series of strata was thus formed resting unconformably upon the Eocene, and unconformably overlaid by the Upper Miocene and Pliocene. It constitutes the Pegu system of Burma, and the Mekran system of Baluchistan.

Kojak shales.

The flysch facies of this system in Baluchistan is known as the Kojak shales, an almost unfossiliferous formation, occasionally containing, however, fossiliferous bands with *Nummulites intermedius*, *N. vascus*, and other fossils of Oligocene age.

Calcareous zones of Sind and Baluchistan.

In the neighbourhood of what was once the shore of the ocean in which the flysch was deposited, the sediments acquire a calcareous facies and become highly fossiliferous. In Sind and in Baluchistan the fossiliferous facies is divided into three principal divisions, the Nari, Gaj, and Hinglaj. The Nari includes the Middle and part of the Upper Oligocene. Its lower division frequently consists of massive nummulitic limestones resting with varying amounts of unconformity on the nummulitic limestones of Eocene age. It is the last horizon rich in large nummulites, principally *N. intermedius* and *N. vascus*, accompanied by lepidocyclines of the group of *L. dilatata*. In the Upper Nari the foraminifera attain their highest development, the Burmese species

Nari series.

Gaj series.

L. Theobaldi Carter, being as much as seven inches in diameter. Other characteristic Nari fossils are *Montlivaltia Vignei, Breynia multituberculata, Eupatagus rostratus, Lucina columbella, Venus Aglaurae.* The Gaj consisting of shales and coral limestones is of uppermost Oligocene age. Its leading fossils are *Lepidocyclina marginata, Breynia carinata, Eupatagus patellaris, Echinolampas Jacquemonti, Vicarya Vernueili.*

Hinglaj series.

The Hinglaj series, well developed along the Mekran Coast, in the Persian Gulf Islands, in the Irrawaddi Valley and Andaman Islands, consists principally of clays and sandstones and conglomerates with a few calcareous bands. The characteristic foraminifera in Burma and the Andamans are *Nummultes Niasi and Amphistegina Niasi.* The Hinglaj series is mainly of Burdigalian age (Lower Miocene), the uppermost beds being perhaps Helvetian (Middle Miocene). These uppermost beds contain numerous large pectens, the commonest species being *P Vasseli.*

Granitic intrusions.

Corresponding in age with a portion of the Pegu system are the great intrusions of granite, of diorite of augite-syenite, and of porphyries, that cut through the Eocene rocks of Baluchistan forming some of the highest hill ranges, such as the Ras Koh, the Khwaja Amran. Of the same age are the Tertiary granites of the Himalaya.

Petroleum, salt, and sulphur.

Other products of this igneous activity are the petroleum of Burma, Assam and the Punjab, and in all probability the salt-marl and salt deposits of the Salt-range, as well as many deposits of sulphur. The petroleum owing to its inferior density as compared with water has collected along the axes of anticlines in the Pegu system, wherever a layer of argillaceous rock has provided an impermeable roof. Gases have also

collected along these anticlinal crests, and are apt to find their way to the surface through fissures, producing the mud-volcanoes that often rise along the outcrops of these anticlinal arches. There are four principal groups of mud-volcanoes, situated respectively along the Eastern and Western borders of the Arakan Yoma, in the Gomal Valley along the Afghan-Baluch Frontier, and along the Mekran Coast.

Mud-volcanoes.

In the Punjab, the equivalents of the Pegu system are known as the Murree beds; in the Himalaya as the Kasauli and Dagshai.

The coal-seams of Assam and Burma occur in the Pegu system and are of Oligocene age.

In the Mari hills of Baluchistan, some beds containing *Mastedon angustidens* and other Middle Miocene fossils probably belong to the upper part of this system.

THE SIWALIK SYSTEM.

THERE are no typical marine deposits in India newer than the uppermost beds of the Pegu system. The main upheaval of the Himalaya and of the mountains of Baluchistan and Burma took place during the Middle Miocene, after which nothing remained of the ocean that formerly occupied their site but a number of basins isolated from one another in which the strata known as Siwaliks, principally clays, sandstones and conglomerate were deposited. Like all inland seas, these basins were subjected to variations in their degree of saltness that were prejudicial to the development of aquatic organisms. Hence the remains of animals of this class are scanty. Some of the conglomerate beds, especially in the Upper Siwaliks, are of fluviatile origin, and may be regarded as alluvial fans.

The great thickness of the Siwalik formation especially at the foot of the Himalaya indicates a gradual deepening of the furrows in which they were deposited, somewhat analogous to the gradual subsidence indicated by the enormous thickness of the flysch.

In Pliocene times, these beds were upheaved during the final phase of mountain-growth of the Himalaya, after which the only earth-movement that has taken place is a comparatively gentle warping that has affected certain regions of Peninsular and extra-Peninsular India and of the Indo-Gangetic plain in Post-Pliocene times. In the Himalaya, the final upheaval was sufficiently violent to thrust the older rocks over the newer ones in a north to south direction, producing the structures known as thrust-planes. The structural peculiarities of the Himalaya have been elucidated principally in the works of Medlicott and of Middlemiss.

The chief interest of the Siwalik formation resides in the remains of extinct animals that have been made known to the scientific world through the researches of Cautley, Falconer, and Lydekker. The bones and teeth of these animals are found principally in the conglomeratic layers at the base and at the top of the series. Those found at the base are of Upper Miocene (Pontian) age, and contain a fauna contemporaneous with that of Pikermi in Greece. Amongst the numerous extinct genera of this fauna may be mentioned *Dinotherium*, *Mastodon*, *Hipparion*, *Helladotherium*, *Hyænarctos*. The upper conglomerates are of Pliocene age and contain the living genera *Elephas*, *Equus*, *Ursus* and many others, all of them represented, however, by extinct species.

Siwalik fauna.

Owing to the abundance of silicified tree-trunks, the Siwaliks are sometimes spoken of as the "fossil-wood-group."

Fossil wood.

The Siwaliks constitute the southern fringe of the Himalaya, and are largely developed in the Punjab, in Baluchistan, in Assam and in Burma. The Cuddalore sandstones of the east coast of the Peninsula probably belong to this System.

Cuddalore sandstones.

THE QUATERNARY ERA.

It is during the final Pliocene uplift that the Himalaya and many of the most important ranges of the globe attained their maximum height. Since then denudation has gradually lowered their altitude. The growth of these numerous mountains, coupled as it seems to have been with a temporary fall of the sea-level, due perhaps to the subsidence of portions of the sea-floor, caused a remarkable change in the climatic conditions of the globe, producing the temporary glaciation of high latitudes that has received the name of Glacial Period.

Glacial Period.

The continental ice-sheets of high latitudes and the mountain glaciers advanced and retreated several times during the Glacial Period, these oscillations coinciding to a large extent with alternately moist and arid periods. The traces left by these changes of the degree of humidity constitute the record of the Glacial Period in countries nearer the Equator.

The ultimate fate of all large continental areas has been the definite establishment of arid and desertic conditions through the gradual desiccation and filling up of the Inland basins that still subsisted after the final Pliocene upheaval.

Indications of the Glacial Period in the mountains of India have not been clearly recorded, the question having scarcely received any attention. There are distinct indications, nevertheless, of the rapid desiccation, since the termination of the Glacial Epoch of the countries forming the north-west portion of the Empire. This desiccation has become aggravated to a marked degree even during the historical period.

It is not certain whether at the end of the Pliocene upheaval an arm of the sea still separated the Himalaya from the Indian Peninsula, but if this were so, it soon became filled by the products of the disintegration of the Himalaya, and in this manner originated the great alluvial plain of the Ganges, which now links the Peninsula together with the Asiatic continent. The great depth of the Ganges alluvium, as revealed by borings, indicates that in its case also subsidence must have proceeded simultaneously with deposition.

Formation of the Ganges alluvium.

Except in the neighbourhood of the delta, the greater portion of the alluvial plain is above the level of the highest floods of the Ganges and its tributaries, indicating that this area has been upheaved, or that the delta region has been depressed within relatively recent times. The presence of a mass of ancient alluvium, known as the Madhupur jungle north of Dacca in the midst of the delta region, further indicates that a certain amount of disturbance must have occurred. The existence of ancient alluvial areas enclosed within rock basins along the course of some of the Peninsular rivers, such as the Narbada, Tápti and Godávári, points to the same conclusion, and it is evident that a certain amount of irregular warping has affected India in Pleistocene times. In consequence of these physical changes, the ancient alluvium and the one still in process of formation can be readily distinguished from one another. They are known in the vernacular as "bhángar" and "khádar." In geological age, they correspond with the two main divisions of the Quaternary era, the Pleistocene and Recent. The Pleistocene age of the bhángar or older alluvium is clearly shown by the remains of numerous extinct animals amongst which may be mentioned *Elephas antiquus*, a characteristic species of the

Older and Newer alluvium.

Pleistocene of Europe, and various extinct species of horse, ox, rhinoceros, hippopotamus. Contemporaneous with these are the earliest remains of prehistoric man in the shape of stone implements belonging to the "Chellean" or amygdaloid type, the earliest type of the earlier stone age.

Prehistoric man.

Implements of the amygdaloid type have been found embedded in "laterite," a ferruginous material, which is formed as a superficial alteration of rocks in regions subjected to "monsoon" conditions, that is, to alternately wet and dry seasons. The effect of lateritic weathering is to remove the silica of rocks, leaving a concretionary mass consisting of hydrates of iron, aluminium or manganese. The silica is redeposited over large areas as a jaspery layer often pseudomorphous after the rocks which it gradually replaces. These siliceous replacement rocks are often observed in the neighbourhood of extensive spreads of laterite.

Laterite.

When the laterite is very free from silica and contains locally a large excess of the hydrates either of iron, aluminium or manganese, it constitutes valuable ores of these metals.

The laterite is largely of Pleistocene age, but some of it may still be forming at the present day, while there are important masses of the same material that were formed in Eocene or even earlier times. It has already been mentioned that stratigraphical breaks are often disclosed by a layer of laterite indicating an interval of continental conditions.

Some of the "raised beaches" observed all round the coasts of India at altitudes of as much as 100 feet are probably Pleistocene. The consolidated wind-blown calcareous sand largely made up of foraminiferal tests, which occurs

Raised beaches.

along the coasts of the Arabian sea and is largely used as a building material under the name of Porbandar stone, is also probably Pleistocene.

Probandar stone.

There are two regions of Pleistocene and Recent volcanic activity situated along lines of dislocation in the curved system of ranges on either side of the great Himalayan "arc." The eastern one situated in the "Malay arc" follows the inner or eastern side of the Arakan Yoma, and its continuation the Andaman Islands, the best known volcanoes being Pupa, Narcondam Island, and Barren Island.

Recent volcanoes.

The latter situated furthest from the Himalaya is the newest and only active cone of the series.

Along the western or "Iranian arc," the largest volcano within the Indian Empire is the extinct Koh-i-Sultán in the Nushki Desert.

Here also the cones become newer as one recedes from the neighbourhood of the Himalaya: west of the Koh-i-Sultán, the Koh-i-Taftán situated in Persia is still active. All the abovementioned volcanoes are andesitic.

Oscillations of the relative sea level during the Recent Period are indicated by such features as low-level raised beaches, the oyster-bed lately discovered in Calcutta, the submerged forests of Bombay and the East Coast.

Numerous minor changes due to marine denudation, to fluvial sedimentation, to alterations in the course of rivers, earthquakes, landslips, the growth of deltas, cyclones, and other actual causes have been observed during the historical period. Here the task of the geologist comes to an end, and we enter the realms of Physiography, Archæology, and History.