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THE GEOLOGY OF SOUTH AFRICA

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THE GEOLOGY OF SOUTH AFRICA

BY

ALEX. L. DU TOIT

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WITH 41 PLATES, 73 TEXT-FIGURES, AND A GEOLOGICAL MAP

THIRD EDITION

REVISED AND ENLARGED

EDITED AND PREPARED FOR PUBLICATION

BY

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PREFACE TO THE THIRD EDITION

THE revision of this book has proved a difficult but rewarding task. Intensive search during the Second World War has succeeded in gathering a heterogeneous mass of fresh data, little of which has yet been published. It has revealed furthermore that not a few current ideas and generalisations have been too simple, or even erroneous. Such applies particularly to those ancient and unfossiliferous assemblages of strata the relative ages and correlations of which are still beset by many uncertainties, that demand the application of advanced physico-chemical measurements for their solution.

Largely to the special economic importance of these primitive formations, and of the Witwatersrand System in particular, has the expansion of the present text been due, but the claims of Archaeology have not been overlooked, although evidence on many vital points of Quaternary Geology is still lacking. An increase in size has been inevitable despite every endeavour at compression.

The Geological Map is again, with the kind permission of the Union, Southern Rhodesian, and Basutoland Governments, based on their official Geological Surveys, together with other available information, thanks being specially due to the Anglo-American Corporation through Dr. J. Austen Bancroft for the results of reconnaissance surveys in the Kaokoveld.

In so far as the Union of South Africa is concerned the following acknowledgment is willingly made: "Extracts from Geological Survey Publications published under Government Printer's Copyright Authority No 201 of the 15th December 1938."

Most of the text-figures have been redrawn, the majority by Mr. John L. Turner, while for illustrations I have been indebted to Drs. Rogers, Hall, Frommurze and Young, Prof. Wellington, Mr. J. Burmester, the Directors of the South African Museum, the British South Africa Company, and the South African Railways and Harbours.

In addition to very helpful criticism from Dr. H. B. S. Cooke and Mr. Leslie E. Kent I am, as before, under great obligations

for information so generously given, inside the Union, by colleagues and friends too numerous to mention individually, by the staffs of the Geological Survey and Universities, and outside the Union by Drs. B. Lightfoot, A. M. Macgregor, H. Martin, E. J. Wayland and E. J. R. Way, and by my Portuguese confrères Dr. Alexandre Borges and Dr. Pires de Carvalho of the Department of Mines, Territory of Moçambique.

In conclusion, to the publishers for their active co-operation in these difficult times, a special tribute is due.

ALEX. L. DU TOIT

PINELANDS, CAPE TOWN
January 1948

EDITORIAL NOTE

AT the time of his death in February 1948, Dr. du Toit had almost completed the revision for the text for this third edition of *The Geology of South Africa* and he left among his papers a series of notes concerning certain sections which remained for final revision.

At the request of members of his family and with the approval of the publishers I undertook the task of completing the preparation of the revised edition and of arranging and supervising the drawing of the geological map, for the revision of which the author had made a few sketches but which had not been completely compiled by him.

The completed text and re-drawn map were in the publisher's hands by July 1950; but unavoidable delays have occurred in bringing them to the state of publication.

I have endeavoured to leave the text in the state in which the author prepared it. Since his death, however, important new facts have accumulated and certain new views, particularly on problems of correlation, have been promulgated by geologists working in South Africa. Where these latter have differed materially from those held by the author I have drawn the reader's attention to them by means of editorial footnotes intended to direct him to the various papers in which the pertinent information is to be found.

The drawing of the geological map was undertaken by Mr.

John L. Turner, and my thanks are due to him for the interest he displayed in its production. I am also grateful to members of the staff of the Geological Survey of the Union of South Africa for helpful discussion of certain points dealing with recent discoveries.

S. H. HAUGHTON

PRETORIA
July 1953

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ABBREVIATIONS USED IN THE FOOTNOTES

Am. J. S.	American Journal of Science, Newhaven, Conn.
Amer. Miner.	American Mineralogist.
Ann. de Palaeont.	Annales de Paléontologie, Paris.
Ann. Mag. Nat. Hist.	Annals and Magazine of Natural History, London.
Ann. Rep. G. C.	Annual Report of the Geological Commission, Cape of Good Hope, Cape Town.
Ann. Rep. G. S. Tvl.	Annual Report of the Geological Survey, Transvaal, Pretoria.
Ann. Natal Mus.	Annals of the Natal Museum, Pietermaritzburg.
Ann. S. A. Mus.	Annals of the South African Museum, Cape Town.
Ann. Transv. Mus.	Annals of the Transvaal Museum, Pretoria.
Beitr. ang. Geophysik	Beitrage für angewandte Geophysik.
Bull. Geol. Soc. Amer.	Bulletin of the Geological Society of America, New York.
Bull. Inst. Min. Met.	Bulletin of the Institute of Mining and Metallurgy, London.
Dep. Min. S. W. A.	Department of Mines, South-West Africa.
Ec. Geol.	Economic Geology.
G. J.	Journal of the Royal Geographical Society, London.
Geol. Mag.	Geological Magazine, London.
Geol. Rundsch.	Geologische Rundschau.
Hand. Reg. Geol.	Handbuch der regionalen Geologie.
Int. Geol. Congr.	International Geological Congress.
Jnl. Chem. Met. Min. Soc.	Journal of the Chemical, Metallurgical and Mining Society, Johannesburg.
Journ. Geol.	Journal of Geology, Chicago.
Min. Journal	S. African Mining and Engineering Journal, Johannesburg.
Mineral. Mag.	Mineralogical Magazine.
Monatsber. D. Geol. Ges.	Monatsberichte, Deutsche Geologische Gesellschaft.
Neu. Jahr. f. Min.	Neue Jahrbuch für Mineralogie, u. s. w.
Palaeont. Zeits.	Palaeontologische Zeitschrift.

P. G. S. S. A.	Proceedings of the Geological Society of South Africa, Johannesburg.
Proc. Rhod. Sci. Assoc.	Proceedings of the Rhodesian Science Association, Bulawayo.
Proc. Roy. Soc.	Proceedings of the Royal Society, London.
Proc. Zool. Soc.	Proceedings of the Zoological Society, London.
Q. J. G. S.	Quarterly Journal of the Geological Society, London.
Rec. Alb. Mus.	Records of the Albany Museum, Grahamstown.
S. A. A. A. S.	South African Association for the Advancement of Science.
S. A. Geogr. Jnl.	South African Geographical Journal.
S. A. J. I.	South African Journal of Industries, Pretoria.
S. A. J. S.	South African Journal of Science, Johannesburg.
S. Rhod. G. S.	Geological Survey of Southern Rhodesia.
T. G. S. S. A.	Transactions of the Geological Society of South Africa, Johannesburg
T. R. S., Edin.	Transactions of the Royal Society of Edinburgh.
T. R. S. S. A.	Transactions of the Royal Society of South Africa, Cape Town.
Trans. Inst. Min. Eng.	Transactions of the Institute of Mining Engineers, London.
Trans. Inst. Min. Met.	Transactions of the Institute of Mining and Metallurgy, London.
T. S. A. P. S.	Transactions of the South African Philosophical Society, Cape Town.
Union S. A. G. S.	Geological Survey of the Union of South Africa, Pretoria.
Zeit. Ges. Erdk.	Zeitschrift der Gesellschaft für Erdkunde, Berlin.
Zeit. Prakt. Geol.	Zeitschrift für praktische Geologie.

Attention should be directed to the publications of the Union Geological Survey by A. L. Hall: *A Bibliography of South African Geology*, Mem. 18, 1922; Mem. 25, 1927; Mem. 27, 1931; Mem. 30, 1937, and *A Subject Index to the Geological Literature*, Mem. 22, 1924; and to S. H. Haughton, *Lexicon de Stratigraphie*, vol. i (Africa), London.

CHAPTER I

GEOLOGICAL PRINCIPLES

Erosion. Accumulation. Time. Types of Deposit. Facies. Consolidation. Attitude. Earth Movements. Unconformities. Overlap. Systems. European Classification. Scope. Continental Drift.

Erosion.—The traveller in this country must often have been impressed by the habitually turbid nature of not a few of the rivers—a peculiarity embodied in such names as " the Vaal " or " the Modder River "—which must have conveyed to him an impression of the large amount of finely-divided waste from the land that must be in process of transfer to the ocean. Numerous gashes and furrows in the soil in much of the territory, even in the semi-arid parts, laying bare the harder rocks, help to confirm him in that opinion, and he concludes rightly that the country must be wearing away at an extremely slow, though by no means infinitesimal, rate.

Although it is impossible to enlighten him as to the rate of such erosion for the entire area of South Africa, some striking figures are available for a very limited section, but which are probably more or less representative for the whole country. The quantity of suspended matter passing Orange River Station throughout an average year—much exceeded under abnormal rainfall—has been computed at over 50,000,000 tons, which ignores, however, the very considerable proportion of dissolved substances in the waters of the Orange River. Additional data show that the annual " load " borne by the combined Orange and Vaal just below their junction is equivalent to the removal from their catchment area of 35,000 square miles of a layer 2/3000 of a foot in depth. In other words, this represents *a general lowering of the surface at the rate of one foot in about* 1500 *years.*[1] It is true that the Orange River system receives but small additions in its lower reaches, but, on the other hand, the steeper gradients of the various rivers on the south, south-east, and east of the continent, coupled with the much higher rainfall in those

[1] In the past twenty years the rate of such erosion has increased progressively.

quarters, would suggest a rate of erosion for the entire country not lower than that quoted.

Granted sufficient time, therefore, the continental plateau would be reduced to an undulating surface of slight relief, while the products of its degradation would have become spread out off its coasts, though, as the land became worn down, the rate of its erosion would obviously grow less and less.

Accumulation.—From data like those given above it follows that the time required for the accumulation of a certain thickness of sediment in the ocean can on certain assumptions be calculated approximately. Estimates ranging from one foot in five centuries to one foot in one century have been made for average types of deposit, including both fine and coarse materials, which enable us to obtain a grasp of the truly considerable time involved in the accumulation of such a deposit as the marine Bokkeveld beds with a thickness of about 2500 feet—a relatively thin Series as it happens. Even allowing for the possibility that the non-marine rocks may have accumulated much more rapidly, millions of years must on the most conservative of estimates have been occupied in the deposition of the 24,000 feet of strata composing the Witwatersrand System.

It is worthy of remark that the material deposited upon the ocean floor must have been worked over again and again by the currents before attaining its ultimate resting-place, and that silts accumulating over a lengthy period may have been scoured away and their place taken by fresh sand or mud. It is not improbable indeed that *each surface of bedding* in the stratified rocks is the final outcome of repeated deposition and erosion under water, which has involved the consumption of much time.

Geological Time.—While such figures based on the rates of erosion and sedimentation convey a rough idea of the periods that can have been consumed in the building up of certain of the geological systems, the total time involved can only be guessed at. First, in the majority of cases subsequent denudation has removed the top of the system, so that its original maximal thickness remains a matter for conjecture. Second, this method cannot measure the "time-value" of *unconformities*, of which there are many, and some of which must certainly represent periods of enormous duration involving the wearing down of a

mountainous region to an absolute plain, as, for example, during the interval just prior to the deposition of the Table Mountain Sandstone. This applies more forcibly to the earlier formations, intensely folded and injected by granite, in which sometimes neither the true order of succession nor the thickness has been established.

The investigation of the *radio-active content* of some of these very ancient rocks does, however, supply the needed information : for example, the determination by Holmes of an age of approximately 1500 million years for certain intrusive granites in Moçambique Territory comparable with those of Rhodesia. This figure, obtained from the " uranium-lead ratio " in the zircons of the granite, is, however, based upon several assumptions, but, even with liberal allowances, that figure will serve to indicate the tremendous age of this pre-Cambrian formation composing the framework of the African continent. His latest (1946) calculations have given 875 million years for the presumed middle pre-Cambrian post-Kheis but pre-Nama pegmatite of Gordonia. The earliest of the fossiliferous beds in South Africa, those of the Bokkeveld Series, were deposited just about 300 million years ago.

Types of Deposit.—Under the potent influence of sun, frost, rain, and wind the rocks exposed to those elements are in time broken up and disintegrated, the boulders ultimately gravitating into the valleys, to be carried forward by the rivers and to be rounded and worn during their transport. The condition finally attained by this material will in no small degree depend upon its particular course and ultimate destination.

(a) *In the Ocean.*—The pebbles and coarser sand will be deposited first, the finer-grained material farther away from the coast, the finest silt being carried long distances before settling —frequently to the edge of the continental shelf—thus helping to extend that feature. There will hence accumulate inshore a mass of conglomerates and grits with a generally well and regularly-bedded series of sandstones and dark shales farther away, probably also limestones formed out of whole or comminuted shells, calcareous algæ or bryozoa ; terrestrial life will usually be absent. The Cretaceous of Pondoland forms an example.

(b) *In Lakes.*—Had the rock waste been dropped in a large lake, such as Tanganyika, deposits of rather similar type would

have accumulated. Current-bedding might be prevalent in the sandstones, the grey shales would be well laminated and perhaps ripple-marked, but limestones would not be present. Life would be represented by occasional fish remains, stems or leaves of plants. As an instance may be quoted the Upper Ecca beds of Natal.

(c) *In Deltas.*—A broad fan, but with imperceptible slope seawards, would be built up by repeated layers of sand and silt, just as is the case with the Zambezi River. The sandstones would be erratic in their development, strongly and irregularly current-bedded with perhaps occasional pebbles and drift-wood, while the shales would be sandy, variable, and poorly laminated. Except at the outer edge of the delta the fossils would mainly be plants and fresh-water mollusca. The Middle Ecca " Coal Measures " doubtless represent such a deposit.

(d) *In Interior Basins.*[1]—In other cases the sands and muds may periodically have been swept down from the rising ground over a broad plain, there, as the moisture evaporated, to build up a sheet of sands and clays. The stratification would tend to be irregular, the base of the sandstones uneven, while " wash-outs " might be common and many of the sandstones highly false-bedded, since some of the material would tend to be re-arranged by the wind. The clays would be poorly-bedded and frequently of a red and green colouring with occasional calcareous nodules ; ripple-marking and sun-cracks could be expected. The remains of animals and plants might be anticipated, also fresh-water or land mollusca. The Beaufort Series appears to have been formed under such conditions.

(e) *In Deserts.*—Finally, the transport might have been done solely by the wind under an arid climate, resulting in the solid formations becoming buried beneath sand and dust from the disintegration of the ranges enclosing the area. There would be a marked absence of lamination, the sandstones would frequently possess a reddish colour and display intense false-bedding, while the sand grains would not uncommonly be well rounded and the mineral fragments but slightly weathered. Fossils would be distinctly scanty. The Kalahari Sand forms a good instance.

[1] This term has to be used, failing a more expressive description, to indicate a vast flat subject to periodical flooding and desiccation—an enormously extended " vloer " or " pan " in fact.

The above describes in a very general way the *five main types* of deposits to be found among the geological formations the world over, namely: (a) *Marine*, (b) *Lacustrine*, (c) *Fluviatile* or *Deltaic*, (d) *Basin* or *Continental* (in a restricted sense), and (e) *Æolian*; but gradations from one to another are characteristically to be met with.

Occasionally, too, an important part may be played by ice, as in the curious Dwyka conglomerate of *glacial origin*, while sometimes the process of sedimentation may have been interrupted by the pouring forth of lavas, as in the case of the basalts building up the highlands of Basutoland.

"**Facies.**"—While over a limited area a single type of formation has tended to be deposited, such is generally not the case over a very large region. Deltaic deposits must naturally pass at their outer margin into marine or lacustrine sands and muds, and so on. Consequently, when a particular geological formation has a wide distribution, it is common to find a change of character, mainly lithological, setting in with distance—a *change of phase or facies*, as it is called.

Thus the Ecca "Coal Measures" of Natal, apparently deltaic in their nature in that Province, are found to pass in the Transkei into the "basin-like facies." The thick limestones, probably marine in origin, of the Nama System in Namaqualand dwindle to the north-east and are replaced by shales.

The likelihood of such "phasal variation" becomes of importance in the correlation of far-separated patches of strata that may have been deposited simultaneously, though under different physiographical conditions. Formations composed largely of conglomeratic beds or of volcanic material are liable to great and sudden variation from point to point, not only in the nature of their materials but in the thickness of the individual rock-groups, as is finely illustrated by the Koras Series near Upington.

Changes in the thickness, either of a minor subdivision or of the entire series, are so universal that the uniformity in this respect of the majority of the great lithological divisions in South Africa is extraordinary and really worthy of notice. Some of those formations can be traced through hundreds of miles showing comparatively little change either in composition or in thickness; for example, the Cave Sandstone of the Stormberg Series. At other times, however, a group may swell out enormously when

traced in a particular direction, as is the case with the Black Reef quartzites in the Transvaal on being followed round from Potgietersrust into the Drakensbergen in the east, when they become at the same time differentiated into several distinctive lithological groups, some of which are now quite coarse in grain.[1] Such an increase in the thickness and grain-size of the sediments generally denotes approach towards the source from which the materials were derived.

Consolidation.—Originally laid down in the friable state, the various types have since become consolidated into more or less compact rocks through various influences, such as by their own weight, by heat, by the circulation of water bringing about the solution and deposition of mineral matter, by earth movements and the pressure resulting therefrom and sometimes by igneous intrusions. Gravels tend to become hard conglomerates, sands are changed to sandstones or into indurated quartzites, muds are converted into shales or even into highly cleaved slates, while under thermal influences they may have become altered (metamorphosed) into tough flinty rocks (hornfels) or even into crystalline schists. Geologically, of course, all materials, whether consolidated or still incoherent like dune sands, are known as "rocks."

Attitude.—Through their mode of formation, nearly all the sedimentary rocks were originally deposited in layers that were either horizontal or diverged but slightly from horizontality. Layer was superimposed on layer, sometimes of a single grade of material alone, sometimes of alternations of coarse and fine stuff, etc., thus building up the sequence of the "*stratified rocks.*"

But, although the strata can still be observed lying in this original attitude, occasionally over wide areas, such as in the Great Karroo (Fig. 44), at many other places they are found tilted up at angles that may even reach the vertical (Fig. 6), or they are discovered, hard and soft alike, bent into folds or even into remarkable crumplings (Plate XV). The intensity of such disturbance is in a very rough way dependent upon the age of the formation, the earliest strata being usually intricately crumpled, whereas those only lately laid down are naturally still undisturbed.

[1] The supposedly thick Black Reef quartzites of the Transvaal Drakensberg have more recently been shown to consist mainly of rocks of pre-Transvaal age, unconformably overlain by Black Reef of normal thickness (Editor).

Since such folding has not infrequently operated within very restricted zones, there are many exceptions to the above generalisation, the older formation remaining undisturbed in close proximity to tilted younger beds, as in the case of the Table Mountain Sandstone and the Beaufort beds on the coast a little to the north of Port St Johns.

Moreover, the beds may have been elevated thousands of feet from their original position close to or below sea-level. This may have been effected either by simple vertical uplift with hardly any tilting, as with the horizontal Tertiary limestones containing large oyster shells building a plateau overlooking the town of Uitenhage, or by the bulging up of the strata during their folding, as, for example, with the marine Bokkeveld beds in the area around Touws River.

Earth Movements.—Folding and elevation have been effected by movements within the crust of the earth, the causes of which it is unnecessary to discuss here, but which are usually confined to relatively narrow belts. It will be sufficient to state that the form taken by the outer shell of the earth is determined largely through equilibrium between the outer, less dense, and more siliceous portion resting upon a heavy, more basic, and feebly-plastic substratum.

The continents would appear to stand above sea-level mainly because they are built of materials somewhat lighter than those composing the ocean floor. The continued erosion of the land-masses makes them lighter, while, on the other hand, the deposition of the waste on the ocean bottom weighs down the latter. There will consequently be a tendency for the land to rise and for the sea-floor to sink, so as to attain to a new position of equilibrium. This tendency towards the re-establishing of a balance between the continental and oceanic areas is expressed by the term *isostatic adjustment.* Erosion may fail to keep pace with uplift or the reverse may be the case. Occasionally the basin of sedimentation becomes filled up entirely, but quite often the trough receiving the silt, if very long and unstable, continues to deepen.

In the latter case, generally following a prolonged period of erosion and deposition, a stage can arise when for several reasons the material in the belt of sinking or "*geosyncline*" becomes greatly weakened, while deeper down a transfer of molten matter occurs, some of which may even burst out at the surface. Deprived

of its support and unable to withstand the enormous lateral pressure, that section of the crust within the trough of subsidence becomes squeezed into many folds and may eventually be pushed up to form mountain ranges, while the old worn-down land surface some distance away may, on the other hand, subside. The relative position of land and sea may thus be reversed : the newly-born mountains proceed in their turn to be denuded and to furnish rock-waste, and another *orogenic* or *revolutionary cycle* in geological history is initiated. During such an upheaval volcanoes may come into being, or the igneous matter may be squeezed out through fissures to produce lava flows or to consolidate below the surface in the form of sheets, dykes, and occasionally bosses.

Of these revolutions—each one involving an enormous period of time characterised by steady erosion, sedimentation, and subsidence, and culminating in a presumably shorter interval of compression, upheaval, and igneous injection—there have been more than half a dozen in South Africa. The total time occupied by each cycle will correspond roughly to that known as a *geological epoch*, and the sediments laid down during that particular period will embrace a *geological system.*

Unconformities.—Arising out of such processes the newly-deposited sediments may be spread horizontally over a surface composed of the older stratified formations—not infrequently folded—or possibly upon an eroded floor of granite or another kind of intrusive rock, the basal beds of the younger formation coming to rest *unconformably* upon the older groups. If this floor had been in preparation for a lengthy period, the land surface would have been worn down to a more or less regular " peneplain," so that, when later on it was buried beneath sediments, the latter would rest evenly though unconformably upon the older rocks, and their basal bed or beds would tend to be regular and persistent. Such for instance is the case with the Black Reef Series forming the bottom member of the Transvaal System. On the other hand, where the preceding period of erosion had been brief, the old surface might still be rough and uneven, whereupon the basal beds of the younger formation, as could be expected, would be irregularly developed : for example, in the case of the Table Mountain Sandstone of Zululand or the Cretaceous beds around Uitenhage (see Fig. 54).

To a certain extent, then, the nature of the unconformable

contact will provide evidence of the relative magnitude of the period during which the land was being worn down by erosion, and during which its waste was being carried off and deposited elsewhere.

The time-interval corresponding to such a period of steady denudation, and so leading to the production of a stratigraphical "break," must occasionally have been of immense magnitude. On the Rand the Black Reef passes evenly within a distance of only a few miles across the planed-down edges of the entire Ventersdorp and Witwatersrand Systems, so as to rest upon the Old Granite, which means that a thickness of well over *five miles of rock* must first have been removed in this locality; as to what became of this material we have practically no indication.

Overlap.—While in all the cases cited the younger formation rests upon the tilted edges of the older groups, and the "angular discordance" is obvious, it sometimes happens that sediments failed to be deposited locally or were subsequently removed by erosion, after which the area sank evenly and became buried again; in such a case certain beds, represented elsewhere, are missing in the locality in question.

The break in the succession may sometimes be indicated by slight angular discordance, as in a certain section in the Dolomite at Campbell west of Kimberley; while it may sometimes be denoted only by a conglomerate at the bottom of the succeeding strata containing fragments of the underlying beds, as is found at the very top of the Dolomite in the Transvaal; but under certain circumstances the break may not be visible, and the existence of such a gap can perhaps be deduced only from the succession elsewhere, by detailed mapping, or from the fossil assemblages present. Such is the case with the great transgression of the Stormberg Series over the Ecca in the central and northern Transvaal, in which, as it happens, the actual plane of overlap is not seen owing to the lack of suitable exposures and the relationship has largely to be inferred from borehole sections. In Zululand a study of the fossils collected suggested that the Senonian stage of the Cretaceous had overlapped on to the Albian stage, yet without obvious unconformity. This phenomenon is usually styled a "*disconformity*."

Systems and Series.—As remarked earlier, the strata laid down within the period of an entire geological revolution represent

what can be termed a "system," and have been formed under comparatively steady or else progressively altering geological conditions, modified very frequently by disturbances due to oscillations of the land relatively to the sea, or arising out of climatic variations. In but a few places, therefore, will one system be found to pass up with perfect conformity into the next, such a relationship being necessarily confined to a limited tract, mainly on the borders of the region affected by the disturbances.

Such a passage, for example, is to be found between the Ventersdorp and Witwatersrand Systems in the area directly to the south of the Rand, or between the Karroo and the Cape Systems in the southern part of the Cape Province. From the very way in which they have developed, there ought somewhere to be an unconformity between each system and the previously formed one; not infrequently indeed the older one has furnished detritus out of which the younger has in part been built.

These huge accumulations of strata—one, two, or more miles in thickness—are, however, far too large for convenient use and hence have had to be divided into "series" and these in their turn sub-divided—very largely on lithological grounds as it happens, which indirectly betoken differing geological and geographical conditions. The smallest units are, of course, individual layers or bands, only the more characteristic or persistent of which would be of value from the stratigraphical viewpoint; for example, the "Main Reef Leader" on the Rand or the "Gus Seam" in the Vryheid coalfield. A thicker assemblage of one type of sediment or of beds carrying one kind of fossil can be termed a *Zone* or *Horizon*, such as the "White band" of the Dwyka Series or the "Endothiodon Zone" of the Beaufort Series in the Cape. Larger assemblages, including sometimes one, but generally more, rock-zones traceable over a wide area, can be called *Groups* or *Stages*, such as the Hospital Hill Quartzites. Stages in their turn build up *series* and series again help to make the *systems*.

Taking the latter as each representing a single great revolutionary cycle, the series would mark out minor events differing somewhat in their characters. Thus the Cape System embraces three series: the Table Mountain Sandstone, a huge unfossiliferous deltaic accumulation, the succeeding Bokkeveld beds, an assemblage of fossiliferous marine sediments, and the Witteberg

quartzites and shales, possibly lacustrine in origin. In this particular instance the succession of events was (1) prolonged planing-down of the land; (2) steady subsidence; (3) increased subsidence and sinking beneath the ocean; and (4) silting up of the sea. The Bokkeveld beds themselves are divisible again into quite a number of distinct stages, each involving the temporary deposition of sands instead of muds. It ought to be made quite clear, however, that the respective time-intervals corresponding to the various "stages," "series," etc., are likely to be only very approximately of equal value.

Lava flows that were poured out while sedimentation was in progress are always considered to form part of the stratified succession, but it is not customary to include in the systems, series, etc., any of the large intrusive bodies of igneous rock, such as the numerous granitic masses. Since the injection of such huge volumes of molten matter was largely the outcome of intense crustal movements, bodies of such a nature seem most frequently to have been introduced into the strata during the *period of transition* between one system and the next.

The European Classification.—In Europe, where the science of Geology took its rise, the great divisions of the "stratigraphical column" have to no small extent been based upon the fossil contents of the strata. Since biological evolution has been enormously dependent upon geological conditions, it follows that there is a strong tendency for pronounced changes in the lithological and geological characters of the containing rocks to be reflected in the fossil floras and faunas.

The scarcity of fossiliferous beds in South Africa has on the contrary obliged us to rely for the most part upon distinctive lithological characters for both major and minor divisions, although the growth of knowledge is enabling the closer "zoning" of the Karroo and Cretaceous Systems to be effected on lines similar to those employed in Europe. A further difficulty has been experienced arising out of the migration of organic forms, known as "faunal evolution." Thus the fauna evolved in the Devonian Ocean that formerly covered the southern part of the Cape developed characters considerably different from those in Europe, though more like those evolved in North America and very close indeed to those in South America. Such faunal variations naturally prevent exact comparison from being made

with the type Devonian of Europe. The many uncertainties that even today exist in regard to correlation have unquestionably been a great handicap to the proper understanding of the geology of this country, and the majority of our visitors have been much perplexed for these reasons.

Moreover, it unfortunately happens that few of the great revolutionary cycles were absolutely universal, in consequence of which it is found that the " diastrophic " periods in South Africa do certainly *not coincide* with those in Europe. Nearly every important break in South Africa, palæontological as well as stratigraphical, happens to fall somewhere within one of the European systems, and each more or less well-marked unconformity between the systems in the Northern Hemisphere is usually represented in this country by continuous deposition :—

" Cretaceous " . .	Cretaceous Jurassic
Karroo . . .	Triassic Permian Carboniferous
Cape	Devonian Silurian

This very largely accounts for the difficulties experienced in attempting to classify our strata according to the standard accepted nomenclature of the Northern Hemisphere. The Karroo " System " actually straddles the Palæozoic and Mesozoic eras.

The absence of all except indistinct traces of life in the beds older than the Devonian in this country makes their correlation with the pre-Devonian strata of Europe and North America practically impossible, and has unfortunately compelled the adoption of a multitude of formational names of purely local origin. Nevertheless, advances will be made in the near future in this as well as in other directions.

The Scope of Geology has to be regarded as more than a mere record of the occurrence, distribution, character, thickness, and relationship of the rocks and of the localities and horizons of their fossils. It must deal with the far wider problems of the deposition of the stratified systems, of the former geographical conditions not only in this but in the neighbouring continental masses, in the remarkable changes of land and sea during the

past, and in the variations of climate during that enormous period of time covered by the geological record. It should also provide material for the interpretation of the Earth, of its structure and catastrophic history. It should treat of the former life of this country and of the evolution of the successive floras and faunas that culminated in the appearance of Man. By its means explanation should be forthcoming for the origin of the geographical and physiographical features of this land, of the nature of its soils and of the movements of its underground waters, while, of the highest importance to the mining engineer, it must set forth the occurrence and nature of the vast stores of *mineral wealth* with which the prosperity and future of South Africa are so intimately bound up. Such will be attempted in the following pages.

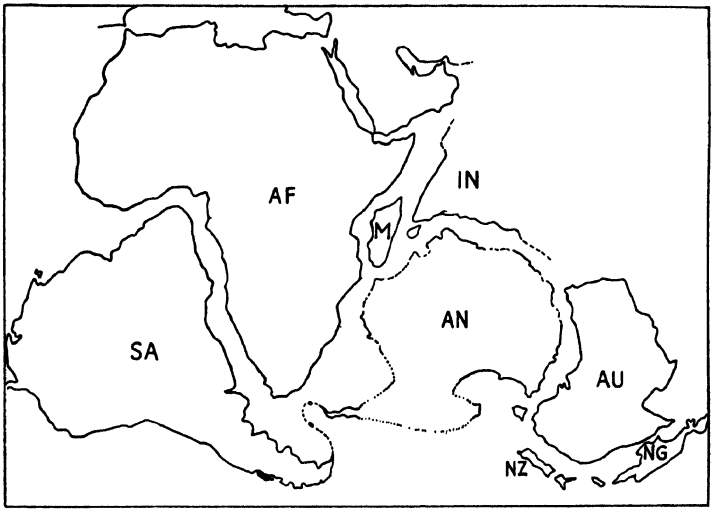


FIG. 1.—Suggested scheme of Continental Grouping under the hypothesis of "Continental Drift."

Continental Drift.—Evidence has been accumulating in support of the hypothesis by Taylor and Wegener that the portions of the former great southern continent of "Gondwanaland," represented by South America, Africa, India, Australia and Antarctica, were formerly set closer together in the geographical sense, as suggested in Fig. 1, and that they reached their present

positions through the fracturing of that continent and the lateral dispersal of the various fragments by " drifting " or " sliding " with the marine waters entering between them to form the Atlantic and Indian Oceans.

The extraordinary, though well-established, similarities and analogies displayed by those several lands in respect of their stratigraphies, orogenies, volcanisms, past climates, faunas, floras, and physiographies thereupon become more clearly and logically explicable than under the orthodox view that the parting oceans originated through the subsidence of huge sections of a far greater parent continent. The deduced position of South Africa right between South America and Antarctica should particularly be noted.[1]

[1] For details see A. L. du Toit, *Our Wandering Continents*, 1937.

CHAPTER II

OUTLINE OF PHYSICAL GEOGRAPHY AND GEOLOGY

Plan. Drainage. Altitude. Geological Structure: Archæan Platform, Witwatersrand and Ventersdorp Systems, Transvaal and Nama Systems, Waterberg, Matsap and Umkondo Systems, Cape System, Karroo System, Cretaceous and Tertiary, Igneous Activity. Stratigraphical Table.

Plan of the Sub-Continent.—Africa south of the Zambezi has a wonderfully regular and symmetrical outline, quite shield-like, with an area of over one and a third million square miles. Its heart is constituted by the *Kalahari Region*, a huge sand and bush-covered dry territory—miscalled "desert"—devoid of running water excepting in the extreme north, and with the solid geological formations deeply buried beneath Tertiary and Recent deposits, save for a few rocky chains projecting through this covering, as along the southern side of Lake Ngami. Around its borders ridges of rock make their appearance and become more and more numerous, the superficial deposits get thinner, while the ground-level rises generally, and the region passes by degrees into an encircling belt of much-diversified country, which is from 100 to over 500 miles in breadth. Outside the latter the ground falls fairly rapidly, though rather irregularly, towards the coast.

In the remarks which will follow there will be mentioned features both topographical and geological which will reveal the striking *symmetry* of this end of the continent.

Several factors have conspired to destroy this simple regularity, chief of which is the unsymmetrical distribution of the rainfall, in its turn dependent on the oceanic and atmospheric circulations. The cold Benguella current is mainly responsible for the aridity of the sandy coastal belt between the Cape and Angola with its trivial winter precipitation of 1 to 5 inches annually; the warm Moçambique current for the high summer rainfall of the semi-tropical belt between Natal and the Zambezi of up to 50 inches. This contrast in the amount and incidence of the precipitation on the two sides of the continent tends to explain very largely the lack in correspondence of the principal river-systems in the east and west respectively.

Drainage.—On the western side the rivers are few and only the Berg, Olifants, Orange and Cunene are perennial; of these the last two—the largest be it noted—not only take their rise within centres of high rainfall but receive no important contributions throughout the lower part of their courses. Between the Orange River mouth and Mossamedes the coastal strip, part

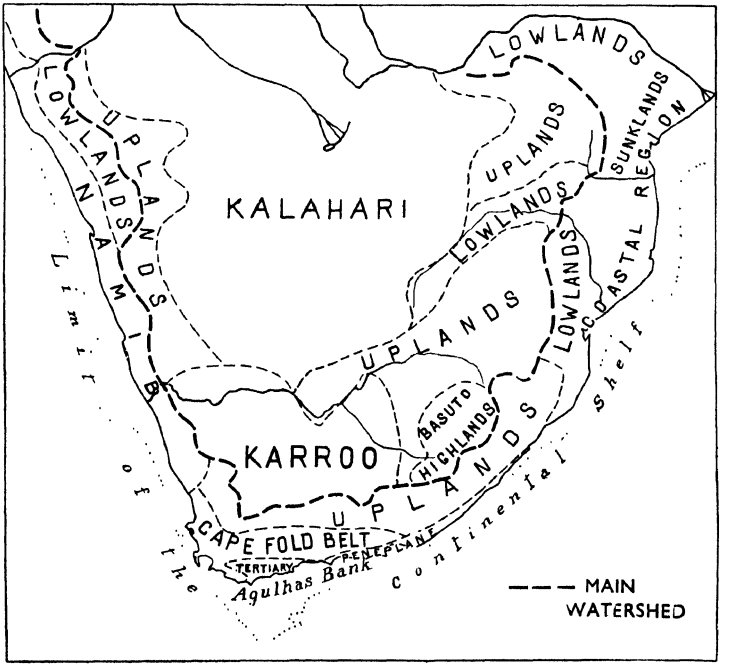


FIG. 2.—Physiographical Regions of South Africa, showing the Main Watershed or "Great Escarpment."

of which is the Namib, is extreme desert. In the south owing to the moderately high winter rainfall the rivers rarely cease flowing, but all the important ones, such as the Gouritz, Gamtoos, Sundays, Fish and Kei, actually originate in the interior region of summer rains behind the mountain girdle and pass through the latter to the sea by means of deep gorges with courses transversely to and marvellously independent of the trend of these great west-east meteorological as well as geographical barriers (Fig. 2).

On the eastern side under the higher precipitation of between 20 and 40 inches—mainly during the summer months—even small streams are perennial and the run-off is generally moderate, sometimes high. The " Okavango-Kafue-Zambezi " river-system forms almost the " mirror reflection " of the " Vaal-Orange " drainage, while the Fish River of South-West Africa constitutes in a way the counterpart to the Limpopo. Since the majority of the larger rivers arise upon the African plateau, their gradients may, over stretches, be high ; sometimes there are waterfalls, *e.g.* the Rua Cana on the Cunene, Aughrabies on the Orange, Victoria Falls on the Zambezi, etc., while rocky bars or rapids may occur in their channels within or just before reaching the coastal belt. Enclosed within the above drainages, the Kalahari Region possesses only a few dry channels, which function for a brief span during very wet seasons.

Altitude.—Accepting the Union as typical of South Africa, one half is standing at between 3000 and 5000 feet above sea-level. There is a fair amount of symmetry exhibited in the relief of the land. The Kalahari constitutes the centre of South Africa and has an average altitude of between 3000 and 3500 feet, but rises gradually to meet the engirdling territory at a level of between 3500 and 4000 feet, except at those places where there is free communication with the exterior lands ; for example, along the Zambezi, between Francistown and Palapye—where the interior connects with the Limpopo ; in Gordonia—where the dried-up and " fossilised " system of the Molopo and Nossob leads southwards to the Orange ; on the west—where the plain which it makes terminates along the Fish River valley ; and in the north-west—where the surface generally ends at the top of an escarpment facing seawards. It is largely bush country, with the deep sandy soil thrown up in the south-west into brilliant red dunes, in great part, however, fixed by vegetation.

The sparsely-timbered and broken ground of the Windhoek and Waterberg districts in the north-west finds its equivalent in the high-standing but more wooded belt which the boundary line between Southern Rhodesia and Portuguese East Africa follows ; in each case the highest point—Mount Omatako in the west and Mount Ingangane in the east—exceeds 8000 feet above sea-level. The Main Escarpment running almost due south from Maltahöhe through Namaland, Namaqualand, and Calvinia is duplicated in

the east by the Drakensberg as far southwards as Swaziland, while, most curiously, to quite a considerable extent identical geological formations and structures enter into the constitution of these two plateaux. In the east many points along the crest exceed 6500 feet, in the west only a few rise to over 5000 feet; the face of the western feature is quite bare, while that of the eastern on the contrary supports many patches of valuable forest.

The north-south running volcanic chain of the Lebombo 400 miles in length is, however, peculiar to the east and so also are the great dissected basaltic highlands of Basutoland, in places exceeding 10,000 feet in altitude, which have no true equivalent in the Western Cape, though topographically the rugged territory of Namaqualand can be regarded as their diminutive representative. The Stormbergen correspond to the Roggeveld of the west and the two are linked together by the east-west running escarpment which constitutes the main watershed in the centre of the Cape Province.

In the south of the latter and reaching to the southern coast stretches a broad belt of mountain land in which arcuate folds of hard strata having a general west-east trend build long narrow sub-parallel chains known as the Cape Coastal Mountains or "*Cape Fold Ranges*," with their summits rising from 4000 feet in the east to well over 6000 feet in the west. Forming a barrier between the ocean and the interior, they rob the winds of their moisture and so give rise to the aridity of the Great Karroo. Over much of South Africa the main watershed (Fig. 2), termed by Rogers "THE GREAT ESCARPMENT," makes a feature facing seawards, which is essentially independent of geological structure and is slowly retreating inland under erosion.

Æolian sands derived from coastal dunes enter very largely into the composition of the sandy coverings of the coastal regions on both sides of the continent, but erosion of the subjacent rocks under an arid climate has greatly contributed to the formation of the broad western belt, whereas the sand- or soil-mantle of the eastern has been developed in the main through intense weathering of the formations under a high rainfall. The coastal territory in the extreme south, on the other hand, is a well-marked plain of erosion or peneplain, in great part, so far as can be judged, marine in its origin, but now elevated hundreds of feet above sea-level and in active dissection by the present rivers.

Geological Structure.—The numerous and often continuous outcrops, save in the sand-covered regions, together with the large-scale development, regularity and persistence of the major units, have much facilitated geological mapping, thereby countering the vastness of the territory concerned.

No representative fossils have been recovered from any of the older and extensively developed groups, often of great thickness and sometimes separated from one another by unconformities; consequently their positions in the geological time-scale are often in doubt. While it is probable that one or more are so young as the earliest Palæozoic, the bulk are assuredly of *pre-Cambrian age*, though undoubted Cambrian has not yet been identified in Southern Africa.

They have hence been provided with purely local names, but are conveniently known as the *pre-Cape rocks*, though only in few cases can they actually be seen with the Table Mountain Sandstone overlying them.

(1) THE ARCHÆAN PLATFORM.—Schistose rocks of various types, including materials of both igneous and sedimentary origin, such as amphibolite, "greenstone," chlorite schist, phyllite, banded ironstone, quartzite, conglomerate and limestone—extensively invaded by bodies of granitic material and underlain in depth by the latter, and tilted to high angles, foliated and highly altered—are the *oldest formations* known in this continent and represent those classed as *Archæan* in other parts of the world or "*Basement Complex.*" They evidently had a very wide distribution originally, but intense erosion of the complex far down into the underlying granite has removed these ancient schistose groups over all but limited areas. These granites, gneisses, and the now subordinate schists comprise the *foundation or primitive rocks of South Africa.* Some part of this ancient "platform" was then buried deeply beneath sediments and subsequently re-eroded, a cycle that was repeated more than once.

These basement rocks are now exposed within the coastal belt of the Atlantic from Van Rhynsdorp northwards through the Namib to Angola, with a tongue extending eastwards along the Orange River and another towards Gobabis. In symmetrical position on the eastern side of the continent lies a similar belt stretching northwards from Natal through Swaziland and the

eastern Transvaal to broaden out over Rhodesia and the adjacent portion of Portuguese East Africa. Between these two great belts the "Archæan" is covered up save for a few tracts in Griqualand West, the south-western Transvaal, and Bechuanaland, where these old rocks show themselves through "windows," as they can be called, in the mantle of younger strata. There is, however, no reason to doubt their continuity beneath that covering throughout South Africa. These Primitive Systems—Kheis, Damara, etc. (see Table, p. 25)—are of immense importance because of the variety and abundance of their *mineral deposits*.

The granites which are so widely intrusive in these ancient formations—although not all of the same age—are referred to comprehensively as the "*Old Granite*" to distinguish them from certain but more restricted granitic bodies of much later date, though still of pre-Devonian age.

The Archæan makes rolling ground, but through the eastern Transvaal, Matabeleland, and Manicaland it gives rise to picturesque country with "tors," domes, or peaks of bare rock jutting out from undulating or broken bush-clad valleys. In the arid territory of South-West Africa the bare granitic or gneissic ranges produce striking scenery (Fig. 11).

(2) THE WITWATERSRAND AND VENTERSDORP SYSTEMS.—Younger than the "Old Granite" are the well-known strata carrying the auriferous conglomerates of the Rand, followed by the succeeding and closely associated Ventersdorp volcanic group. The former are not limited to the Rand and neighbouring districts, being represented in the south-western corner of the Transvaal and northern half of the Orange Free State and possibly (as the Pongola System) in the south-eastern Transvaal and Zululand as well; but the latter possess a far wider extension, stretching from the Rand across to Bechuanaland Protectorate, Griqualand West, and Prieska.

While thick alternating groups of quartzites and slates, including some laminated ferruginous types, characterise the lower half of the Witwatersrand System, the upper consists mainly of quartzites and grits with pebble-beds, among which are the famous pyritic gold-bearing "bankets" on which the incomparable prosperity of this country has so largely been based.

(3) THE TRANSVAAL AND NAMA SYSTEMS.[1]—Of these assemblages younger than the Old Granite the most important areally are the several quartzite—limestone (or dolomite)—slate—quartzite successions the correlation of which remains uncertain.

(a) *The Transvaal System*—which may prove the older—has its limestone-dolomite member building the Kaap Plateau in Griqualand West and Bechuanaland, where it is overlain by the conformable group of brown jaspery ironstones known as the Griquatown beds. Valuable are its deposits of manganese and iron ores and blue asbestos. In the east the Dolomite and the succeeding Pretoria beds—the equivalent of the Griquatown beds—are represented around Parys, Potchefstroom, and Johannesburg, and extend in an almost complete oval basin (Fig. 27) right across the middle of the Transvaal with the strata dipping inwards beneath a gigantic laccolithic igneous mass known as the " BUSHVELD IGNEOUS COMPLEX." The latter is several hundred miles across, two or more miles thick, and is made by an earlier *Diabase* and *Norite* and a later *Red Granite*, which have jointly produced contact metamorphism on a great scale in the invaded sediments. Important deposits of tin and platinum are connected with its intrusion.

Comparable folded strata, under the name of the "Malmesbury beds," occupy the south-western part of the Cape, where they have been invaded by masses of the " Younger Granite."

Equivalent with the Transvaal System is possibly the Lomagundi System of Southern Rhodesia.

(b) *The Nama System* in the west, along with the Otavi System of South-West Africa, also mineralised, covers a broad belt of slightly inclined strata stretching from Rehoboth southwards through Namaqualand into Van Rhynsdorp, where it becomes flexed.

(4) THE WATERBERG-MATSAP-UMKONDO SYSTEM.[2]—These triply-titled thick quartzitic groups appear in areas and patches over an immense region (Fig. 32), and focus attention because of their characteristic brownish or purplish colouring. Within certain belts there has been strong crumpling.

[1] The correlation of these two systems is not generally accepted by South African geologists, who consider the Nama to be younger than the Transvaal (Editor).

[2] Haughton (*T.G.S.S.A.*, 1950, liii, 205) has suggested that the Matsap System is older than the Waterberg System (Editor).

(5) THE CAPE SYSTEM.—These strata, of probably late Silurian to early Carboniferous age, emerge from beneath the Dwyka Series in the south-west and south of the Cape, and again in Pondoland and the eastern half of Natal, but must die out beneath the Karroo beds in a northerly direction, probably at about a line joining Calvinia to Greytown. The structural symmetry of South Africa is well brought out by this system, running as it does in north-south belts on both east and west joined by an east-west belt on the south. Worcester is situated at the south-western intersection of the foldings, but the corresponding one in the south-east is hidden by the waters of the Indian Ocean.

Triply divided, the thick quartzitic Table Mountain Sandstone composing the lowest member generally builds up—in the folded condition—most of the ranges in the southern Cape, and is responsible in Natal, where it is mostly horizontal, for plateau scenery. Infolded therewith in the Cape come the slaty rocks of the Bokkeveld Series carrying the earliest marine fossils known in this part of the world—of Lower Devonian age. The overlying Witteberg Series contributes lesser ranges made chiefly of bare white quartzites.

(6) THE KARROO SYSTEM.—Almost wholly of continental origin, it was deposited in the interval between the Upper Carboniferous and the Jurassic Epochs. It formerly covered the major portion of South Africa—possibly almost as much as two-thirds, not to mention its indicated former extension outside the limits of the present continent—though stripped off by subsequent erosion over wide areas or buried beneath the younger deposits of the Cretaceous and Tertiary Epochs.

Excepting to the south of the 33rd parallel, where they follow *conformably* upon the top of the Cape System, the beds rest with marked *unconformity* upon all the older formations and not unusually too upon an uneven surface made by the latter. They lie nearly horizontally, save (*a*) in the eastern Transvaal, where along the 32nd meridian they have been bent downwards towards the coast in a monoclinal flexure continued through Moçambique to the Lower Zambezi, and (*b*) in the southern part of the Cape, where, despite their much greater thickness, they have been involved in the intense folding of the Cape System (Fig. 3).

These folds flatten out to the north and the practically undisturbed Karroo beds make a continuous covering extending

through the Karroo, Orange Free State, and Natal, into the Transvaal. Interrupted by the Lower Orange River valley and by the ancient ridges of Prieska and Griqualand West the formation is discovered in Gordonia and in South-West Africa, where it stretches as far westwards as the Fish River and northwards as the Rehoboth and Gobabis highlands, and probably underlies

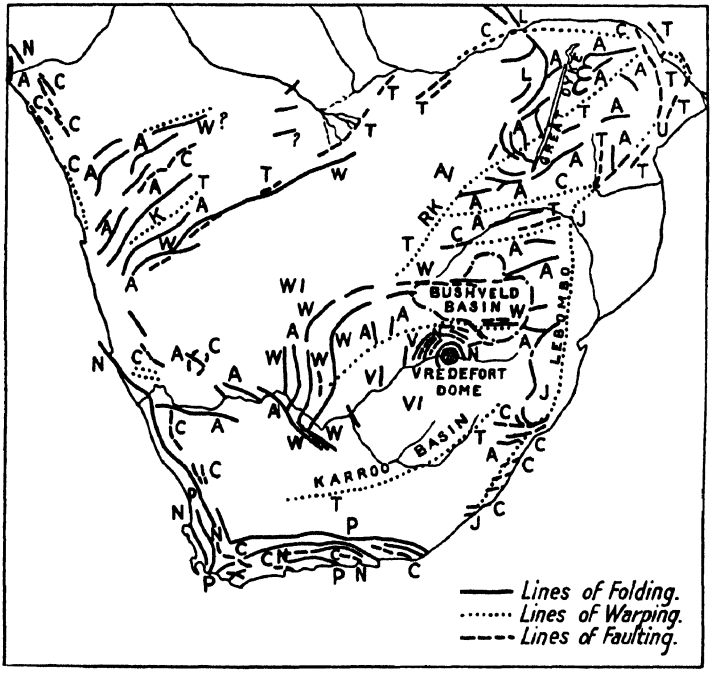


FIG. 3.—Tectonic Map of South Africa, showing chief directions of Folding, Warping, and Faulting. The letters indicate movements that are :—A, post-Archæan ; V, post-Ventersdorp ; N, post-Nama and post-Transvaal ; L, post-Lomagundi ; W, post-Waterberg-Matsap ; P, Permo-Triassic ; J, Jurassic ; C, Cretaceous or Cretaceo-Tertiary ; T, Tertiary ; RK, Rhodesia-Kalahari axis ; K, Khomas axis ; U, Urema " sunk-lands."

most of the western and southern Kalahari. Near the Atlantic, in the Kaokoveld, there is again a wide tract and one also forms the Congo-Cunene-Zambezi watershed far to the north.

Outliers exist in the south-western Transvaal, Springbok Flats, Lydenburg, north-western Waterberg and eastern Bechuanaland, while Rhodesia and Manicaland are surrounded by an

almost complete girdle of Karroo, which is in places broad and is largely low-lying. Patches in the Victoria district serve to connect with the wide region between Bulawayo, Victoria Falls, and Lomagundi, and to emphasise the former extensive distribution of the system.

Excepting in the regions north of the 22nd parallel the *base* is made by the celebrated *Dwyka Conglomerate* of glacial origin and of Upper Carboniferous age. It is followed by a great thickness of sediments in the lower part of which are contained the enormously large and valuable *coalfields* of Natal, Transvaal, and Rhodesia. The fossils consist of occasional plants, reptiles, and amphibians indicating a Permian to Triassic age. The succession ended in vast outpourings of *basaltic lavas*, such as build the impressive highlands of Basutoland or underlie the sand north of Bulawayo.

Followed from south to north, not only do the various subdivisions get thinner, but there can be made out *two overlaps* within the system, one near the base and the other not far from the summit, so that in places, *e.g.* central Transvaal and central Rhodesia, the very topmost sediments or even the succeeding basalts come to transgress directly over the much more ancient formations.

(7) THE CRETACEOUS AND TERTIARY.—There is a break in the geological record covering the whole of the Jurassic except within the Lower Zambezi valley perhaps, where sediments and volcanics are found, but the Lower Cretaceous is represented by the continental and marine beds of the Uitenhage Series in the south of the Cape Province, while marine clays and limestones ranging in age from Lower Cretaceous to Eocene fringe the Pondoland, Natal, and Zululand coasts and possibly underlie the entire coastal region of Portuguese East Africa. Younger marine Tertiaries border the southern coasts, where they reach a considerable altitude, the eastern, and the western in the neighbourhood of Lüderitz.

The vast central Kalahari region is mantled with red to grey dune sands, concealing surface limestone, soft sandstones and clays, which have a good thickness in places and probably extend back from the Pleistocene well into the Tertiary Era.

(8) IGNEOUS ACTIVITY.—During several periods *Lavas* and *Tuffs* were erupted on an extensive scale, for example in the

System	Formation	Igneous Phase	Earth Movement	European Equivalent	Age in Million Years
Quaternary	Alluvium. Low-level gravels. Surface limestone. Kalahari sand.			Pleistocene to Recent.	0–1
Tertiary	Marine beds of Portuguese East Africa, South-West Africa, Alexandria, Bredasdorp. High-level gravels. Kalahari beds.	Trachyte, nepheline-basalt, etc.	Uplift and Warping.	Eocene to Pliocene.	1–60
Cretaceous	Marine beds of Portuguese East Africa, Zululand, Pondoland, Needs Camp. Uitenhage beds. Embotyi beds.	Kimberlite and Melilite basalt.	Faulting around Africa.	Neocomian to Danian.	60–125
Karroo	Dwyka. Ecca. Beaufort. Stormberg.	Lupata Volcanics. Stormberg Volcanics. Karroo Dolerites.	Cape Foldings.	Upper Carboniferous to Liassic.	150–225
Cape	Table Mountain. Bokkeveld. Witteberg.		Post-Waterberg Foldings.	Upper Silurian to Lower Carboniferous.	225–320
Waterberg	Waterberg. Matsap. Umkondo.	Alkali-Syenites, etc.		Early Palæozoic (?).	(?)
Nama	Kuibis-Nieuwerust. Schwarzkalk. Fish River. Otavi.	Minor Eruptions. Younger Granite. Bushveld Igneous Complex.		Early Palæozoic (?).	(?)
Transvaal	Black Reef. Dolomite. Campbell Rand. Pretoria. Griquatown. Stinkfontein-Kaigas. Lomagundi. Malmesbury.	Minor Eruptions.	Folding.	Pre-Cambrian.	
Ventersdorp	Ventersdorp, Pniel, Koras (?), Deweras (?).	Vast Eruptions.	Folding.	do.	
Witwatersrand	Upper and Lower WWR. Zoetlief. Pongola (?).	Minor Eruptions.	Minor Foldings.	do.	
Primitive	(*b*) Shamvaian. Frontier. Moodies. Damara. Gariep, etc. (*a*) Sebakwian. Bulawayan. Abbabis. Kheis. Kraaipan, etc.	Older Granites. Minor Eruptions. Vast Eruptions.	Various Foldings and Faultings.	do.	

Rhodesian Schists, Kheis, Pongola, Ventersdorp, Transvaal, and Karroo systems, while of *Intrusive Phases* there were at least *four* of granitic as well as many of basic and ultrabasic rocks.

Stratigraphical Table.—On page 25 is given the general succession among the formations, with their equivalent ages so far as can be established; the closer correlation within the various groups will be detailed later in the particular chapter concerned. Great uncertainties attach, however, to the older ones. Each system was usually preceded by a lengthy *erosion-period* and terminated by *horizontal or vertical movements*.

CHAPTER III

THE PRIMITIVE OR BASEMENT SYSTEMS

Nomenclature. Rhodesia and Portuguese East Africa. Transvaal. Zululand and Natal. Cape. South-West Africa. Correlation.

Introduction.—As in other parts of the world, those formations belonging to the dawn of geological history are fragmentary in their distribution, extremely complex in their relationships, and not infrequently problematical in their origin.

Generally, basic igneous rocks—extrusive, intrusive, and fragmental—constitute the very earliest types of which we have any record, being intercalated with and followed by fine-grained sediments—such as slates, limestones, cherty quartzites, and jaspers—and subsequently by varied assemblages in which grits and conglomerates play an important part.

Throughout these extremely remote epochs the crust of the earth appears to have been relatively thin and rather unstable, so that sedimentation was repeatedly interrupted by effusions and injections of igneous matter ranging in composition from ultra-basic to acid, the latter commonly on an enormous scale, to solidify as granite and quartz porphyry, while the metamorphism and the tectonic movements produced thereby were accordingly intense. The complicated nature of the folding, the intensity of the alterations and the impregnation with igneous matter all add to the difficulties in determining the original characters of the beds, their succession, and the geological history of the area. Moreover, the vast amount of subsequent erosion has often left for study only patches which may be hundreds of miles apart, while over wide areas the worn-down complex may be hidden by coverings of younger strata.

The detailed mapping of the pre-Cambrian formations in North America has made manifest the large number of series and groups involved, their frequent lateral lithological variation, the repetition on different horizons of "banded ironstones," and the many unconformities either regional or local, no doubt due to the general instability of the crust in those times.

Much work remains therefore to be done in South Africa

before the precise succession can be made out in the several areas and the origin of some of the more highly altered rock-groups determined; even then the relationships of the various, now isolated, ancient formations may remain uncertain.

Nomenclature.—While the most altered types have been spoken of as schists and gneisses or else termed "Archæan," or even "Proterozoic," the less altered strata have been locally named, wherefore a host of local formational names is already in use to describe the many patches of ancient rocks in South Africa, and there is unfortunately no comprehensive term to embrace them all.

Though it cannot directly be established, the majority of the occurrences are certainly of pre-Witwatersrand age,[1] though it is possible that the Witwatersrand System will be represented among these groups in some outlying region. Furthermore, in three areas at least *two* distinct systems are to be found separated by unconformities, and elsewhere stratigraphical breaks are suspected in the great masses of strata, so that the employment of a single all-embracing System would be inappropriate.

Following Schenck's classification of 1888 the name "*Swaziland System*" has been rather generally used, though with a somewhat different meaning to that conferred by Schenck. The tendency nowadays is to extend it to cover all the formations earlier than the Witwatersrand. The Germans have chiefly employed the title "Primärformation," which is by no means a satisfactory one. Since it is preferable to employ a wide and yet non-committal term, and since formations of *more than one distinct age are certainly involved*, the name "*Primitive Systems*," proposed in 1926, is retained for lack of a better, though its defects are clearly recognised. In Central and East Africa the convenient terms "Upper Basement Complex" and "Lower Basement Complex" have with advantage been employed.

While some authors would include the intrusive granites and orthogneisses with the stratified rocks, such a course does not conform to custom; moreover, in some instances granites of widely different ages are known to occur, hence the proved intrusive rocks will be described separately. It must nevertheless be admitted that the ancient schistose groups include certain types of undoubted—and a still larger proportion of presumed—intrusive origin, which cannot everywhere be separated therefrom.

Measurements of the strontium-rubidium ratio of lepidolites from ancient pegmatites have given ages ranging from 800 to 1250 million

[1] The only locality where actual unconformable position has been observed is a few miles to the north-east of Fortuna, Heidelberg, where slates and banded ironstones underlie the Orange Grove Quartzites discordantly.

years for four localities in South-West Africa and 2100 million for one in Swaziland.[1]

A. Rhodesia [2] and Portuguese East Africa

Distribution.—The salient peculiarity of this region is the fact, as the Geological Map [3] will show, that practically every mining field with its numerous gold mines is situated on a patch of Basement Schists and associated rocks, between which extend wide tracts of more or less barren granite and gneiss.

The largest of these makes in plan a very imperfectly formed letter " G," extending from Belingwe to Bulawayo and curving in a broad band (much hidden by younger deposits) across the Bembesi and Shangani to Que Que, Gwelo, and Selukwe. Another area surrounds Gatooma and sends an arm towards Salisbury, where it forks, one branch running directly eastward and the other curving round to Shamva. To the north-east stretches the Mount Darwin belt and to the north-west the smaller yet more important one of Eldorado. Victoria and Belingwe are both situated on irregularly curving belts, and Gwanda and West Nicholson on a rectangular area. Francistown, in the Tati Concession, stands on another large patch.

A narrow strip trending a little north of east runs through Penhalonga near Umtali, passes Macequece (Masikesi) and spreads to make the Manica Goldfields, while a belt of rather similar rocks constituting the eastern limit of the Archæan crosses the railway about Vila Machado. Within the Portuguese frontier one finds a great development of white quartzites and quartz schists both to the north of the Pungwe River in the Barué district and to the south in the Chimanimani Mountains and the Statonga Range.

In addition to the foregoing there exist in between innumerable smaller, though well-defined, strips as well as huge areas of composite granulites and gneisses; large parts of the country are still only slightly known geologically.

Stratigraphical.—Among the early pre-Cambrian formations of this great region, collectively known as the " Rhodesian or Greenstone Schists," there are today included, though not all developed

[1] L. H. Ahrens, *T.G.S.S.A.*, 1948, i, 23.

[2] A vast amount of detailed information is contained in the various publications of the Geological Survey of S. Rhodesia.

[3] *S. Rhod. G.S.*: scale 1 : 1,000,000, 1947.

in a single area, at least *four distinct assemblages* parted by unconformities, as indicated below [1] :—

(Intrusion of Granites)

Shamvaian or Sedimentary System	Upper	
	~~	Frontier Series ?
	Lower	
	~~	(Orogeny and Intrusion)
Bulawayan or Greenstone System	Upper	
	~~	
	Lower	
	~~	(Intrusion of Granite)
Sebakwian System	(Magnesian Series)	(base unknown)

The prevailing strong foliation and shearing tend to obscure the dip of the bedding, which is usually high.

Intrusive into the Greenstones, though *prior to the "Old Granite,"* are the serpentines and other ultra-basic rocks that have so large a development in Selukwe, Belingwe, Victoria, Filabusi, and Que Que, and are of such economic importance through their huge deposits of chrysotile asbestos and chrome-iron ore (pp. 495, 500).

Mennell [2] first enunciated the important principle that over this great territory the intrusive granite has usually domed-up the schists, largely along anticlinal axes, so that the relative ages of the strata invaded are roughly given by their comparative distances from the major granite bodies. They would indeed seem to have subsided between the uprising batholiths (p. 60), though not according to any regional pattern, and to have experienced generally less erosion and metamorphism over the centre than the periphery of Rhodesia.

Lithological.—Of the prominent rock types the following are the most conspicuous :—

(a) *Greenstones.*—Dominant, these range from greyish tough rocks to highly fissile greenish varieties that can be termed hornblende schists. Although including intrusions, they are largely basic lavas, as shown by the preservation of amygdaloidal and pillow structures and by the association of agglomerates and

[1] A. M. Macgregor, *S. Rhod. G.S.*, 1947, Bull. 38.

[2] F. P. Mennell, Rhod. Mus. Special Rept. 2, 1904 ; *Q.J.G.S.*, 1910, lxvi, 353.

tuffs.[1] The non-foliated kinds, more particularly near the intrusive granite, are darker, have usually had their original pyroxene converted into green hornblende and are known as *Epidiorites*. Basaltic and andesitic kinds predominate, but some have been derived from ultrabasic limburgites or from felsites, while rhyolitic lavas have also been discovered, as in the neighbourhood of Bulawayo.

Associated are fragmental rocks ranging from coarse agglomerates and breccias down to fine tuffs, composed mostly of fragments of similar igneous types, but carrying occasionally lumps of banded ironstone, felsite, and quartz porphyry and grading into true sedimentary conglomerates and grits. Along with the felsitic and fragmental types are puzzling rocks known as " porphyroids." Subordinate are arkoses, dark greywackés, slates, jaspilites, banded ironstones and limestones.

" Pillow-structure," which is indicative of subaqueous and perhaps submarine eruption, is common and is useful for determining the dip of the flows. The sack-like " pillows " range from a few inches to a few feet across with roughly convex upper and flattish or concave lower surfaces, while within the darker chilled crust a vesicular texture can usually be made out. Such structures may be partly or wholly destroyed by shearing.

The original textures are surprisingly well preserved in many of these greenstones (Plate I, Figs. 1 and 2), and even in some of the epidiorites (Plate I, Fig. 3), though recrystallisation has commonly produced clear felspars with needles of hornblende (Plate I, Fig. 4). Some varieties are coarse, passing by degrees into amphibolites. Under shearing these rocks have been converted into hornblende schist or even into chlorite schist with carbonates (Plate I, Fig. 5). The composition of two representative greenstones is given in Analyses Nos. 1 and 2 (p. 580) and one of epidiorite in Analysis No. 3.

(b) *Banded Ironstone and Jaspilites.*—These singular rocks, strikingly developed throughout this territory, appear on various horizons not only in the Greenstones but in the sedimentary series as well, four distinct groups being known in the Gwelo district (Bull. No. 31), though jaspilites become scarcer in the later beds. They occur in beds from a few up to several hundred feet in thickness, are generally considerably folded, and on account of their superior outcrop-hardness and high inclination make chains

[1] A. M. Macgregor, *T.G.S.S.A*, 1921, xxiv, 150; *S. Rhod. G.S.*, Short Report, 14, 1923.

of conspicuous hillocks, though rarely exposed in the stream beds passing through such ridges.

The banded ironstones consist of alternating cherty or quartzose and ferruginous layers, but are variable in composition, all gradations being found, from nearly colourless cherts through brilliant red jaspilites to black rocks striped with red or brown, wherefore they are often referred to as " banded jaspers," " striped cherts," " calico-rock," etc. Rapid variation in character along the strike is common. In depth they are banded in black and white, and composed of layers of quartz (or chert) and magnetite (Fig. 9) ; the rocks are hence strongly magnetic. At the surface some of the magnetite has been converted into hæmatite or limonite. Extraordinary are the minor contortions and puckerings of the laminæ, while the material has often been greatly fractured and recemented with silica ; mineralisation has frequently followed lines of crushing and shear with introduction of pyrite and pyrrhotite.

The bulk of the banded ironstones certainly represent reconstituted fine mechanical or chemical sediments, some, as in the Lonely Mine area, having been followed down into quartz-chalybite rocks. Their great contortion, although the enclosing strata may run evenly, shows that the parent material has yielded to pressure more easily than the adjoining beds. Most of them have probably developed from the oxidation of siliceous muds containing chalybite, greenalite or pyrite. Others again, such as around Gatooma, have arisen from the alteration of felsites (see p. 62). When metamorphosed by the granite, contact minerals such as andalusite and sillimanite have been developed in the ironstones, for instance in the eastern part of the town of Salisbury, at Hartley and Mazoe, while hornblende or grunerite may be present. The conversion of a band into andalusite-corundum granülite has been recorded from Mazoe (Bull. No. 33, p. 29). Interbedded with the banded ironstones are pale mica schists, dark slates, sometimes limestones (or dolomites), as at Concession Hill near Hartley, the Colleen Bawn Mine near Gwanda, at a point 12 miles south-east of Bulawayo, or in the Enterprise Mining Field, where they are grey and coarsely crystalline and sometimes carry amphibole ; calcareous rocks, however, are not so abundant as in South-West Africa.

I. The Sebakwian System.—These, the oldest strata in Rhodesia, were discovered in 1929 unconformably beneath the Greenstones and were styled the " Magnesian Series " because of the associated magnesian rocks of originally igneous composition—banded ironstones being also present. Since then they have been

recognised elsewhere, for example, (*a*) the belt of serpentine, talc schist, magnesite rock, quartzite, banded ironstone and marble striking south through Que Que that was invaded by the Rochdale granite and eroded before the pouring out of the Greenstones (Bull. No. 20), (*b*) the chrome-bearing talc schists at Selukwe (Analysis No. 5), Lower Gwelo (Bull. No. 37), west of the Lonely Mine (Bull. No. 11) and at Shangani, (*c*) the much recrystallised arkoses, greywackés and siltstones in the Antelope Mine area (Bull. No. 21), (*d*) perhaps certain composite gneisses and crystalline schists in Portuguese Territory.[1]

II. The Bulawayan or Greenstone System.—This, the most extensive of the primitive formations, is dominantly of volcanic origin. Almost everywhere its lower contact with the "Old Granite" is an intrusive one, but its actual base can be seen in the section a mile and a half above the Sebakwe Poort near the Globe and Phœnix Mine as a conglomerate up to 300 feet thick standing vertically against the Magnesian Series—containing fragments not only of the latter but of a pre-greenstone granite and pegmatite—followed by banded ironstones, pillow lavas, porphyritic and fragmental rocks, etc. The boulders are smaller than on the Hunyani River at Eldorado, while some bands are full of flattish chert and jaspilite pebbles (Bull. No. 20).

An important break is present within the system over an area extending northwards from Bulawayo to the Umfuli at least (Bull. Nos. 17, 20, 30, 31, 34), which is followed by agglomerates or sediments with occasional conglomerates; otherwise both divisions include similar kinds of material. In the Umfuli area, a sedimentary group with eruptives parts them (Bull. No. 34). Basic intrusions have become converted into hornblende schists.

The principal types consist of (*a*) basic and other lavas, agglomerates, tuffs, arkoses and greywackés, (*b*) quartzites, cherts, jaspilites, banded ironstones, and (*c*) slates and limestones, bands of which, even when narrow, can often be traced for long distances. *Algal structures* have been recorded from north of Bulawayo in limestones carrying some graphite situated well down in the greenstones.[2]

Through their mode of accumulation the groups may vary considerably in composition and thickness, so that the subdivisions for ad-

[1] E. O. Teale, *T.G.S.S.A.*, 1924, xxvi, 112.
[2] A. M. Macgregor, *T.G.S.S.A.*, 1941, xliii, 9.

joining mining fields may not agree save in a general way. Thicknesses are not easily measured, but figures of 14,000 feet and of 22,000 feet for the Lower and Upper Divisions were got at the Queen's Mine north of Bulawayo (Bull. No. 30). The lower portion is represented in the Filabusi area by sericitic quartz schists and quartz porphyries (Bull. No. 27), in Mount Darwin by arkoses, greywackés, porphyroids, hornblende schists and banded ironstones, and in central Mazoe by massive quartzites and quartz schists—the " Maparu Series "—that form ridges (Bull. No. 22).

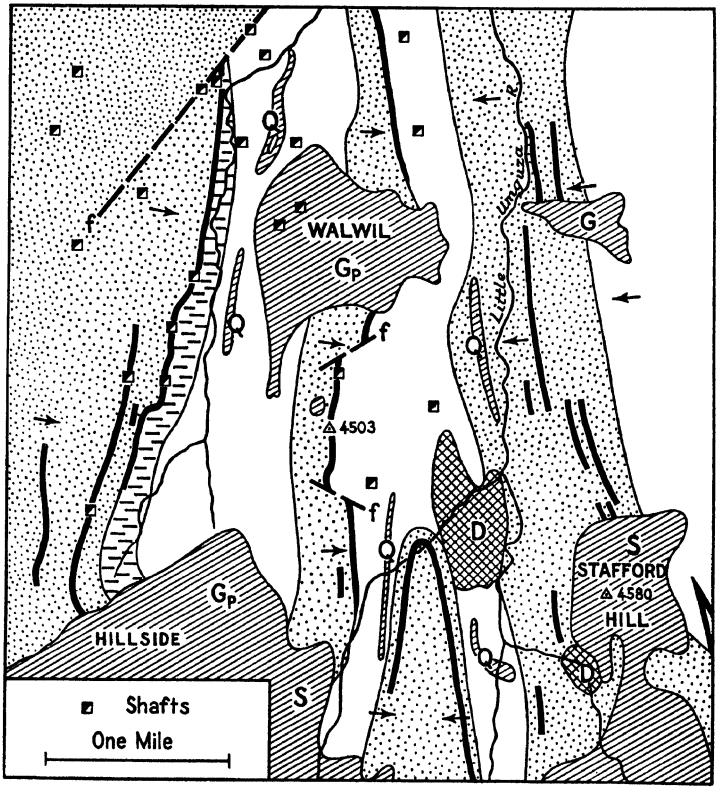
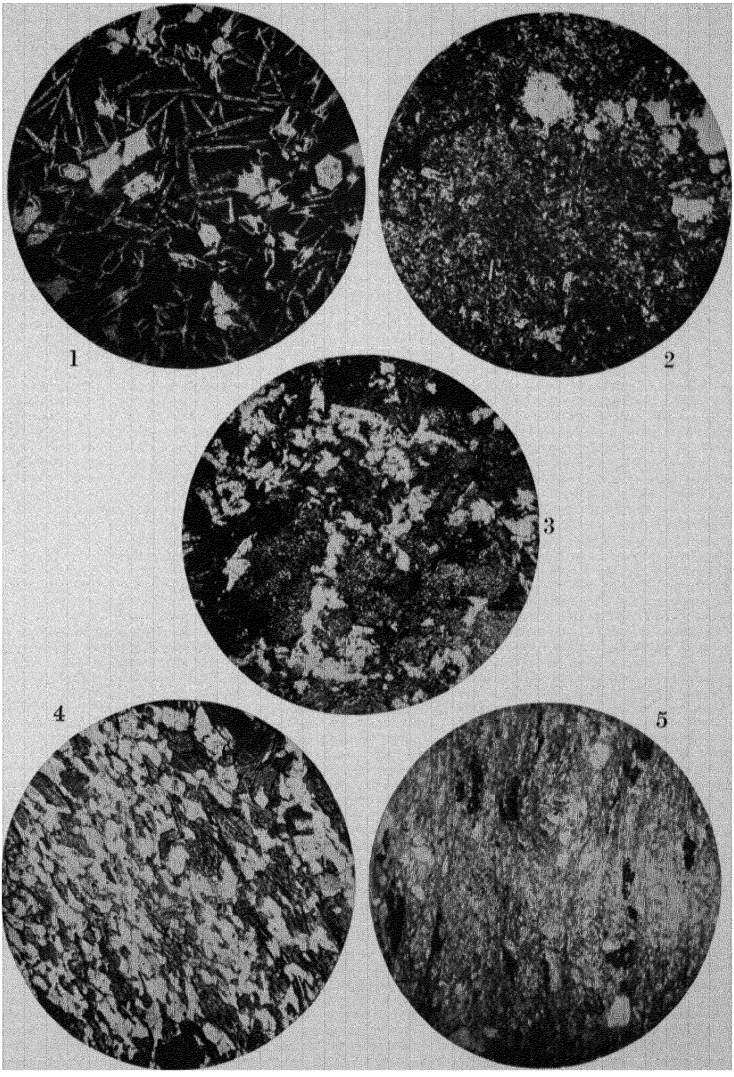


FIG. 4.—Geological Map of a small area just east of Bulawayo (*after* A. M. Macgregor and F. L. Amm). Stippled—Basaltic Greenstones and Hornblende schists; Plain—Andesites with interbedded Tuffs, etc.; Black—Banded Ironstones; Broken ruling—Conglomerate Group; Ruled—Intrusive Rocks, namely :—G, Granite; Gp, Granite-porphyry; Q, Quartz porphyry; S, Syenite; D, Doleritic Greenstone; f, Fault.



Photomicrographs of Rhodesian Greenstones. 1, Limburgitic greenstone, Bembesi; 2, Amygdaloidal pillow lava, Bembesi; 3, Doleritic epidiorite, Bembesi; 4, Epidiorite, Sepamba; 5, Quartz-bearing carbonate-chlorite schist, Bembesi. Each magnified 15 diameters.

[*Face page* 34

III. The Shamvaian or Sedimentary System.—Unconformable to, and folded in with, the Greenstone System and the ultrabasic intrusions in each of the larger mining fields are considerable thicknesses of gritty and conglomeratic strata, including much arkose and greywacké—inclined at high angles and sometimes metamorphosed—that are of much younger age, since they contain pebbles not only of contorted banded ironstone but of granites, etc., intrusive into the greenstones (Figs. 5 and 6). This was first found to be the case with the celebrated " Eldorado Conglomerate " by Mennell [1] in 1910. Intrusive Younger Granite, as at Eldorado and Umtali, nevertheless indicates the antiquity of this formation, which is indeed comparable with the Witwatersrand System. Although thick, measurements are not available, while an intraformational gap is present south of Bulawayo and near Que Que.

Near Sinoia the " *Eldorado Series* " [2] with north-easterly strike lies unconformably upon greenstones, banded ironstones, and sheared felsites (Fig. 26). It consists of an extremely thick group of schistose and much altered feldspathic grits, arkoses, greywackés, and boulder-beds, between which are bands of softer strata, mainly biotite and actinolite schists.

There are three distinct boulder-beds, the lowest 260 feet thick resting transgressively on the older rocks. Owing to intense pressure the boulders have often been flattened, while the matrix —probably argillaceous originally—has flowed around the inclusions and acquired a schistose character ; it is now a biotite-chlorite schist. The boulders range from a few inches to a few feet in length occasionally and consist of granite, granophyre, felsite, quartz, banded ironstone, etc. ; their shape and arrangement are suggestive of deposition by torrential rivers (Gregory).[3]

Trending eastwards through Bindura is the belt made by the " *Shamva Grit Series* " composed essentially of gritty arkoses and greywackés carrying pebbles of granite and other older rocks and with bands of biotite schist, pierced by bodies of granite and gabbro (Bull. Nos. 22 and 33). Because of their composition and high metamorphism certain of these strata were for long mistaken for microgranite.

An equivalent appears to be the " *Ruya Series* " of the Mount Darwin district in a belt curving eastwards—conglomerate, grit,

[1] F. P. Mennell, *Q.J.G.S.*, 1910, lxvi, 353.
[2] A. J. C. Molyneux, *S. Rhod. G.S.*, Bull. 9, 1923.
[3] J. W. Gregory, " The Banket of S. Rhodesia," *S.A.A.A.S.*, 1905, 101.

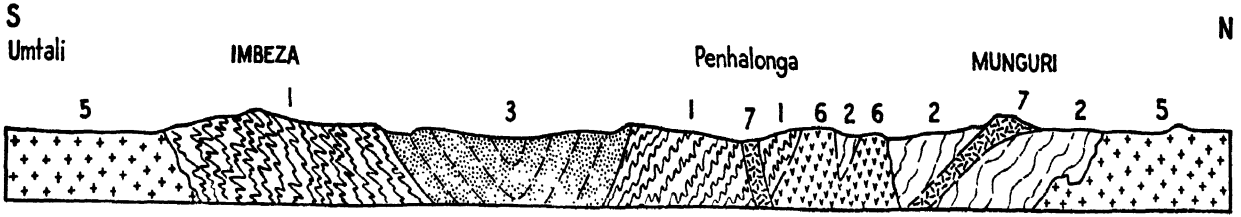


FIG. 5.—Section, 12 miles long, through the Umtali Syncline (*adapted from* Bull. G.S., No. 32). 1, Serpentine and Talc schist; 2, Bulawayan Greenstones and Epidiorites; 3, Lower Sedimentary Series; 4, Upper Sedimentary Series; 5, Basement Granite; 6, Quartz porphyry and Felsite; 7, Dolerite.

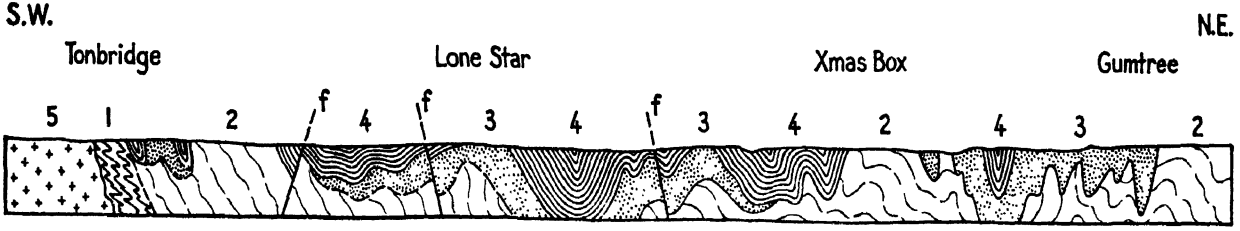


FIG. 6.—Section, 12 miles long, through the Synclinorium, 10 miles S.E. of Bulawayo (*adapted from* Bull. G.S., No. 35). Explanation as for Fig. 5; f, Fault.

quartzite, and mica schist—and largely converted by the enveloping granite into paragneisses with hornblende, garnet, staurolite, etc. (Bull. No. 10). The axis of the Umtali syncline is occupied by the "*Mbeza Series*"—arkoses and dark greywackés with a thick basal conglomerate carrying pebbles of actinolite rock, banded ironstone, gneiss, serpentine, etc.—resting unconformably on schists and penetrated by a few granite stocks (Bull. No. 32) (Fig. 5), and extending eastwards past Macequece.

Near Gatooma a narrow belt of similar beds with quartz porphyry pebbles, with some layers of banded ironstone, and with andesitic to

FIG. 7.—Conglomerate, Sebakwe Poort, Rhodesia, showing flattish inclusions of Banded Ironstone in the intensely hard rock.

trachytic lavas at the top, trends north-westwards through Battlefields expanding into a deep syncline west of Que Que, wherein follows unconformably a higher group of dark grits with bands of conglomerate finely exposed in the Sebakwe Poort (Fig. 7) (Bulls. Nos. 17 and 20). West of the Lonely Mine in the Bembesi Valley is another belt of these folded rocks, averaging 5 miles in width and striking a little west of south, called the "*Ndutjana Series*" (Bulls. Nos. 11 and 30). Its basal conglomerate rests on the banded ironstone to the east, and carries inclusions of that rock and also of the greenstones and felsites. Bluish-grey unsorted grits with fragments of jaspilite pre-

dominate and are accompanied by slates with some banded ironstone and dolomitic limestone, while the whole is cut by intrusions of gabbro.

At Selukwe[1] an identical series of conglomerates, grits, and arkoses is closely folded in with the older schists, being highly sheared and crushed; the mapping suggests an unconformable base. The pebbles run to a foot in size and include quartz, quartzite, jaspers, granite, felsite, and schistose rocks.

South of Bulawayo lies a triangular area of grits, arkoses, etc., passing up into conglomerates, followed, after a break, by a great thickness of phyllites with greywackés, banded ironstones and occasional limestones (Bull. No. 35) (Fig. 6).

Styled the "*Deweras Series*"[2] is a formation appearing on the Umfuli River, north-west of Gadzema Station, in several narrow belts, the largest 17 miles long, with the strata tilted to fairly high angles, reposing with marked unconformity on the Basement Complex and unconformably overlain by the Lomagundi Beds (p. 175). The Lower part consists of somewhat altered lavas of originally basaltic composition—with an impersistent basal conglomerate—and the Upper part of a thick conglomerate—which includes boulders from the lower section—followed by greyish-green false-bedded arkoses with pebble-beds. While conveniently described here, the low grade of alteration and lack of acid intrusions suggest a far younger age than Shamvaian.

IV. The Frontier Series.[3]—This consists of several thousand feet at least of very white, and in places glassy, quartzites alternating with some bands of quartz schists and slates of various colours, giving rise to a belt of extremely rugged ground that trends south-north in Portuguese territory for 100 miles with a maximum width of 12—from the Buzi River to Bandula Station east of Macequece. It has produced some magnificent scenery, as in the Chimanimani Gorge on the road between Melsetter and Vila Pery. In the south the quartzites build the Sitatonga (Statonga) Range, to disappear beneath Karroo basalts. In the centre they rise to 7727 feet above sea-level in the Chimanimani Range, on the west side of which, shortly within Rhodesian territory, they have been raised by faulting against up-tilted younger Umkondo beds. Farther north they form outliers

[1] A. E. V. Zealley, *S. Rhod. G.S.*, Bull. 3, 1919.

[2] A. E. Phaup and F. O. S. Dobell, *S. Rhod. G.S.*, Bull. 34, 1938.

[3] E. O. Thiele (Teale) and R. C. Wilson, *G.J.*, 1915, xlv, 16; E. O. Teale, *T.G.S.S.A.*, 1924, xxvi, 103; C. F. de Andrade, *Esbôço Geol. Prov. Moçamb.*, 1929, 40 and 54. The writer is particularly indebted to Dr. Pires de Carvalho for sketch maps and notes.

capping the summits of the Macuta Range, cut through by the Revue River.

Formerly continuous over a wide region, this series caps higher ground, being sharply folded in some places though undulating in others, jointed and bounded or displaced by cross- as well as by strike-faults. It rests *unconformably* on the schists and banded ironstones, and is traversed by dykes of dolerite, aplite, and occasionally serpentine—as to the east of Melsetter—and is furthermore believed to be intruded by gneiss-granite.

It differs in strike and lithology from the Shamvaian of the Umtali area and from the fact that the Mbeza conglomerates there carry pebbles of serpentine but none of quartzite. The formation is, however, said to resemble the Upper Pongola of the Transvaal (p. 114).

B. The Transvaal

Distribution.—The main occurrences make relatively narrow belts flanked and invaded by granite or gneiss, the central parts of which, owing to certain harder beds, give rise to higher, broken ground.

Emerging from beneath the Black Reef Series in the north-east are two belts trending almost east-north-east, one accompanying the railway from Potgietersrust to Pietersburg and passing through Mount Maré, the other extending through Thabina and Leydsdorp and forming the Murchison Range. A minor east-west belt crosses the upper Letaba River. South of them lies the important belt stretching from Komati Poort through Barberton, sending an arm westwards to Kaapsche Hoop and one curving south-westwards along the Swaziland border and ending in the granite at Oshoek. Patches occur along the Assegai River south and south-west of Vryheid.

Numerous sections display stage by stage the development of banded hornblende gneisses from amphibolites through invasion of the latter by the acid magma, and in such composite granulitic or augen-gneisses garnet is not unusual, while occasional belts of coarsely crystalline marble carrying contact minerals obviously represent relics of invaded sediments, for example in the " Marble Delta " at Port Shepstone in Natal or to the north of the Zoutpansberg and again on the lower Magalakwin River; pyroxene is then not uncommon in the adjacent gneiss. Narrow belts of banded magnetite-quartz rocks carrying sillimanite build the pinnacles of the Los Berg to the north of Pietersburg and the

Blaauw Kop south-west of Messina. These and other para-rocks have been detailed by Sohnge.[1]

Occurrences.—(i) *Mount Maré.*[2]—The 35-mile belt passing through Marabastad shows several thousands of feet of variable and much metamorphosed strata dipping south-eastwards, traversed by an important strike-fault and flanked and penetrated by the "Old Granite." They consist of a basal group of extrusive and intrusive "greenstones" with banded ironstone (variable) on several horizons, followed by phyllites, shales, quartzites, grits, and conglomerates (sometimes sheared and tourmalinised). The latter carry pebbles of banded ironstone, schists and some of an *older granite.* The ironstones make hills such as Mount Maré and the conspicuous Ysterberg. Ottrelite and andalusite characterise certain bands, tourmaline is widespread, while auriferous quartz veins are common.

(ii) *Murchison Range.*[3]—The strata in this belt, 12 miles wide at Leydsdorp, form a deep compound syncline tapering eastwards, flanked and invaded by the prevailing "Old Granite." Prior to the latter there was introduced into the base of the formation, mainly on its northern side, the "Rooiwater Igneous Complex," a gabbroidal body—now much altered to amphibolite and chloritic schists—with two important bands of titaniferous magnetite, as segregations. At the top along the northern side of the belt, a slightly younger hornblende granite was injected.

The formation consists of (*a*) highly sheared quartz porphyries, (*b*) basic lavas, (*c*) quartzites, grits, and schists (with prominent bars of greenish quartzite, etc., such as the Chloritoid or the Antimony Bars), and (*d*) slates and lavas. Peculiar greenish carbonate or carbonate-quartz rocks form broad belts in (*c*) and (*d*), extremely variable in composition, in part sedimentary, in part due to hydrothermal alteration of basic materials, for example at Quagga Kop or the Monarch Mine.

Intrusion and permeation by the Old Granite has, in addition to contact minerals, brought widespread though erratic mineralisation with high-temperature auriferous sulphide deposits of various kinds, mostly parallel to the bedding or schistosity throughout the belt. The other reefs are essentially replacements by arsenopyrite, pyrite, and pyrrhotite with the gold in the sulphides. In the unique Antimony Line the antimony occurs in lenticular lodes as stibnite with some carbonate, the gold being present in both materials but having proved

[1] *Union S.A.G.S.*, 1945, Mem. 40, 27-43.

[2] A. L. Hall, *T.G.S.S.A.*, 1909, xii, 32; *Handb. Reg. Geol.*, 1929, vii, 7*a*, 38; J. Willemse, *Union S.A.G.S.*, 1938, Bull. 12.

[3] A. L. Hall, *Union S.A.G.S.*, 1912, Mem. 6; E. Mendelssohn, *T.G.S.S.A.*, 1939, xli, 249; O. R. van Eeden, *Union S.A.G.S.*, 1939, Mem. 36.

difficult to extract. The only mercury mine in the Union, at Monarch Kop, has been worked during the war as cinnabar in quartz-carbonate lenticles in chlorite-carbonate schists.

In the pegmatite-seamed southern side of the belt *emeralds* have been mined in four localities east and north-east of Gravelotte, as well-shaped crystals in patches of biotite schist near contacts with pegmatite in which beryl occurs.[1]

(iii) *Barberton.*[2]—The great succession of folded rocks frequently referred to in early days as the "*Swaziland Beds*" occupies a roughly triangular area and builds up the rugged Barberton Mountain Land and the neighbouring portion of Swaziland with the folds diverging westwards and south-westwards. The purely sedimentary rocks form the interior and have been given the name *Moodies Series* by Hall from one of the many ranges which this formation builds, and are bordered and supported by schistose and predominantly basic lavas and intrusions, in turn underlain by intrusive "Old Granites." The succession, upwards, is :—(*a*) Onverwacht Series, (*b*) Fig Tree Series, and (*c*) Moodies Series.[3]

(a) *The Onverwacht Series.* With its base and thickness unknown, this has a wide development in the south-west along the Komati Valley near Steynsdorp and in a strip along the Noord Kaap River past Eureka Siding and presumably at other points also around the mountain lands. It is essentially of *volcanic origin*, consisting of highly altered basic lavas followed by or alternating with acid lavas (quartz porphyries) together with interbedded shales, banded cherts, etc.

(b) *The Fig Tree Series.* Following conformably on (a) and including strata previously placed by Hall in the lower part of the Moodies Series, this underlies and is folded with the latter, normally occupying the lower ground, being well exposed south of the Sheba Mine in the Ulundi syncline (Fig. 8), along the Komati Valley and inside Swaziland territory. Essentially sedimentary, it is apparently over 10,000 feet thick and consists of a

[1] J. M. Lagrange, *T.G.S.S.A.*, 1930, 1. *Union S.A.G.S.*, 1939, Mem. 36, 93.

[2] A. L. Hall, *Union S.A.G.S.*, 1919, Mem. 9; *Handb. Reg. Geol.*, 1929, vii, 7*a*, 24; E. B. Papenfus, *T.G.S.S.A.*, 1935, xxxvii, 279.

[3] The original subdivisions and their relationships have become modified through the detailed mapping by the Geological Survey, work which is not yet published, and the following account has been largely compiled from information obtained from Dr. O. R. van Eeden, supplemented from other sources.

monotonous group of alternating slates (some graphitic), banded cherts, greywackés, and grits, with some feldspar porphyry (soda trachyte) at the top. The greywackés carry angular chips of chert and quartzite and resemble those of Southern Rhodesia.

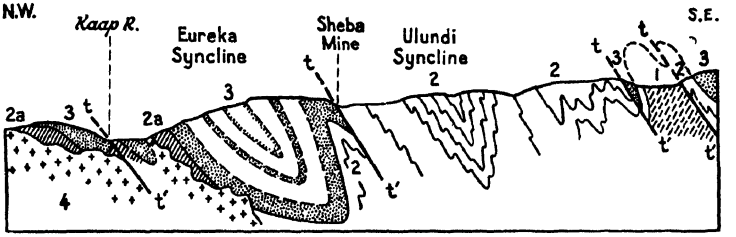


FIG. 8.—Section, 9 miles long, through the Sheba Hills, Barberton (*adapted from* Van Eeden). 1, Onverwacht Series; 2, Fig Tree Series; 2a, Feldspar porphyry; 3, Moodies Series; 4, Nelspruit Granite; t-t', Thrust-plane.

The prominent Ulundi and Sheba " bars " are cherts and the Zwartkoppies " bar " a silicified mylonite. The banded cherty (ribbon) shales may pass into banded jaspers and ironstones and carry iron ores locally, as at the Ironstone Kop south of Malelane and just within Swaziland along the eastern side of the Ingwenya Range from the Komati River to the Havelock Mine (p. 526).

(c) *The Moodies Series.* From 6,500 to 10,000 feet thick, this commences with a prominent group of greyish calcareous to feldspathic quartzites 800 or more feet thick, having a fairly persistent *basal conglomerate* followed by a great mass of sandy slates, phyllites, and greywackés, but including at least two important quartzite members. These quartzites build ranges trending south-west, such as the Makonjwa, Ingwenya, Kobolondo, Saddleback, etc., but their structure has still to be worked out. An inferior *unconformity* is shown by a gradual transgression across the older formation, while the basal and higher conglomerates include pebbles of dark cherts, jaspers, and grits identical with some from the Fig Tree Series, as well as of quartz porphyry and granite—for example on Saddleback Hill, Three Sisters, and Emlembe Mountain—and have in places experienced intense shearing with distortion of the pebbles. All the quartzites show recrystallisation, and carry ottrelite locally. Banded ironstone and jaspery rocks, though less persistent than in the Fig Tree Series, occur in both shale groups. The thick coarse false-bedded quartzites indicate shallow-water conditions.

The dip is principally to the south-east, but there is much isoclinal folding with overturning to the north-west, and, as now delimited, the Series occupies a more restricted area. It stretches in a narrow belt from the Buffalo Range in the east to the Alpine Mine beyond Barberton, expanding and curving in the Eureka syncline of the Sheba Hills, forming deep infolds along the Swaziland border and breaking up into mere cappings on the ridges to the west of the Emlembe Mountain, with a syncline to the west, just north of the Komati Valley. Strong overthrusting with brecciation and mylonitisation on a great scale has been observed by van Eeden, as on the Saddleback Hill and at the Barbrook Mine (Fig. 8).

(d) *The Jamestown Igneous Complex.*—This, a group of highly basic and ultrabasic rocks (mostly serpentinised) that have been converted largely into hornblende, talc, and carbonate schists, is intrusive into all three series. An analysis of such serpentine is given under No. 3. Its relations are in part sill-like, which will explain the repeated intercalation with banded cherts, etc. On the south it forms a belt extending from Komati Poort to near Pigg's Peak; on the north from Malelane to Louws Creek and again from Jamestown to Kaapsche Hoop; in the west from Noord Kaap to the Komati River—bordering the complementary, probably differentiated, De Kaap Granite. That batholithic body —a granodiorite with hornblende—is intrusive into the Jamestown Complex and must therefore be *younger than the Moodies Series* though actual junctions have apparently not been reported. On the south the mass was intruded by the " Old Granite " of Swaziland, perhaps of similar age.

Most susceptible to metamorphism were the Fig Tree shales and greywackés and the calcareous rocks of the Moodies. The combined influence of these intrusive bodies, coupled with the strong folding, has led to the production—mainly in the lower group—of ottrelite, andalusite, biotite, garnet, hornblende, or tourmaline in the slates, and of sillimanite, garnet, cordierite, and biotite in the siliceous types.

Economic.—Near Mount Maré the most important gold mine was the Eersteling, said to have been discovered in 1870. About Barberton finds of gold were made about 1883. The numerous lodes are only rarely within the granite but mainly in the lower parts of the assemblage, the majority lying in the belt running

through Barberton to the Kaap River and up and down the latter, and again just inside Swaziland, *e.g.* Pigg's Peak; only a few mines are situated among the higher strata away from the contact zone (in a wide sense) of the granite. They are commonly related to faulting or thrusting. Most of these deposits are impregnation reefs such as the famous Sheba (see p. 522). Tin occurs in the extreme south at Oshoek and Forbes Reef in Swaziland, in pegmatites in the basic schists. Chrysotile is mined on a great scale by Havelock Asbestos Mines just inside Swaziland, magnesite in the form of veins in serpentine was or is worked at Kaapmuiden and formerly at Malelane, and talc and verdite —a green ornamental variety of serpentine—at Noord Kaap Siding.

(iv) *Piet Retief.*—Forming two areas each ten miles long to the west and south-west of Piet Retief, up the Assegai River, are basic schists and amphibolites, quartzites, quartz-mica schists, banded ironstones, and jaspilites—often extremely contorted—with north-east to south-west strike that strongly recall those of Barberton. Garnet and staurolite have been developed by the intrusive granite.

C. Zululand and Natal

(i) At Nondweni[1] greenstones, veined by the granite, identical with the Onverwacht Series, especially through the presence of black and white cherts, appear as inliers in the Dwyka, and similar beds occur in the lower Buffalo River. Along the Tugela an inverted succession striking east-west is seen of basic lavas and tuffs passing up through chlorite schists into limestones and downwards into hornblendic schists and amphibolite cut by aplite and pegmatite, while banded ironstone, etc., appears at Isibudeni to the east and in Melmoth. Farther down the Tugela these hornblendic rocks become so interleaved with granitic matter as to pass into composite hornblendic gneisses that cover a wide area. A belt of quartz and mica schists with cyanite in places runs eastwards through the Nkandhla Forest. The Lilani Hot Springs near Hermansburg in Natal issue from green schists and limestones trending east-west. Pre-granite intrusions of serpentine carrying seams of chrysotile asbestos are known at the Sitilo and Tugela Randt near Kranskop, also corundum-bearing rocks (marundites).

(ii) *Marble Delta.*[2]—Enveloped by the Old Granite and cut by sheets and dykes thereof is the twisted block of dolomitic marbles

[1] A. L. du Toit, *Union S.A.G.S.*, 1931, Expln. Sheet 109.
[2] A. L. du Toit, *Q.J.G.S.*, 1920, lxxv, 119.

filling the angle between the Umzimkulu and Umzimkuluwana rivers above Port Shepstone known under this name. The rocks are mostly white, cream, or pink, coarsely crystalline, with bands carrying scattered crystals of serpentinised olivine, pyroxene, and phlogopite-mica, sometimes spinel and graphite. Along certain contacts the dolomite has been converted into masses of crystalline calcite. The dolomite is quarried extensively as a source of lime.

D. The Cape and Border of South-West Africa

These rocks are confined to the southern part of Bechuanaland and to a belt west of Prieska that extends to Upington. Isolated strips, the bulk greatly metamorphosed, are numerous in the granite region to the west, particularly in the northern corner of Namaqualand.

(1) *The Kraaipan Series* [1]

This formation, which cannot be less than 10,000 feet thick, makes three important but narrow belts through the Mafeking district trending almost north-south, flanked on either side by granite and gneiss; the beds have been much folded and considerably faulted.

One belt passes through Mosita, one through Pitsani and Kraaipan (extending southwards into the Transvaal and northwards into the Bechuanaland Protectorate), and one through Madibi.

No veins of granite have yet been found traversing this formation in this area, nor does the latter carry contact minerals, yet the granite could well be intrusive. The best section is on the railway at Kraaipan, where the whole formation is dipping eastward at a high angle with the granite brought up again on the east by a large fault.

Conspicuous are banded and contorted black, brown, and red magnetite-hæmatite-quartz schists (banded ironstones), and pale or brilliant red (Fig. 9) massive or striped chert and jasper, which give rise to lines of koppies; the softer strata are rarely seen except in artificial openings, being slates, chloritic schists, and diabase mainly. At Madibi the rocks are thinner-bedded and

[1] A. L. du Toit, *Ann. Rep. G.C. for* 1905, 205; *ibid. for* 1907, 123.

consist of alternations of " magnetic quartzite " and sericite schist, chlorite schist, and calcareous schist.

At Pitsani and Mosita the proportion of volcanic material increases, and the " magnetic quartzites " and cherts form thick bands alternating with great thicknesses of basic lava, in places showing " pillow structures," and sometimes basic breccias and tuffs, quartz porphyries, grits, slates, and limestones. Where the Setlagoli River cuts through the western belt there are four great zones of volcanics and the sedimentaries prove to be those seen in the central belt; the

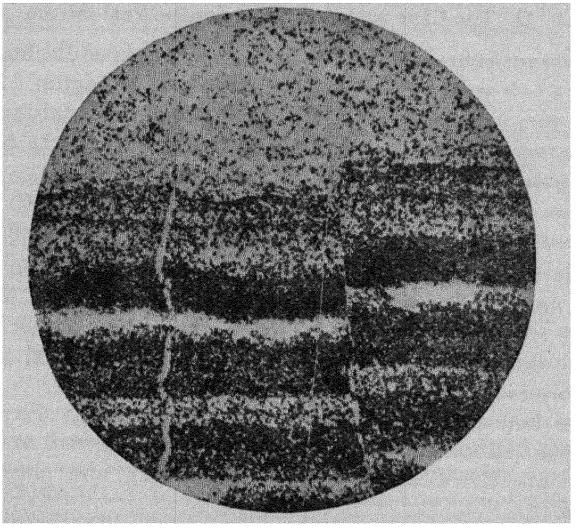


FIG. 9.—Thin Section of Banded Ironstone (quartz-magnetite schist) from the Kraaipan System, showing alternating layers of quartz and magnetite cut by a fault and by a narrow vein of quartz. ×12.

lowest is composed of magnetic quartzites, the second of chert and jasper, and the third is a series of cherts and quartzites. A thick zone of diabase accompanied by some quartz porphyry intervenes between the lowest magnetic quartzite and the granite both at Pitsani and Mosita. Hereabouts fully two-thirds of the formation must be of volcanic origin.

The strata seem to have been subjected to more intense metamorphism towards the south, and the chloritic and hornblendic schists in that quarter are evidently the equivalents of the basic lavas and tuffs seen to the north-west; associated with the banded ironstones are magnetite-actinolite and magnetite-actinolite-enstatite rocks, the

amphibole being allied to cummingtonite. Some of the quartz veins carry gold, notably on Wodehouse Kraal and at Madibi, resembling those in Rhodesia in containing pyrrhotite, while the reef at Madibi carries tellurides. The auriferous reefs at Abelskop and Goudplaats between Pudimoe Junction and Schweizer Renecke in the Transvaal traverse rocks belonging to this formation, which make a belt in the granite crossing the Harts River Valley with a north-south strike. According to Jorissen and van Eeden the granite is here intrusive into the schists.

A large band of magnetite-quartz schists, slates, and interbedded quartz porphyries strikes east and west a little to the north of Takoon, well to the west of Vryburg.

(2) *The Kheis System* [1]

Historical.—In 1874 G. W. Stow applied the name 'Kheis Series to a group of quartzites and mica schists (which in error included the Black Reef as well) that appeared to be the oldest formation in Griqualand West and Prieska. Adopted by the Geological Survey in 1899, that title was altered to *Kheis* in 1907, following the official spelling of the type locality on the Orange River above Upington. Because of associated basic rocks and other kinds its boundaries were extended in 1908, and it was triply divided by Rogers into : (1) The *Marydale Beds*, (2) the *Kaaien Beds*, and (3) the *Wilgenhout Drift Beds*, the second actually representing Stow's original 'Kheis Series.

Nowhere has any base been discovered, all contacts with the Old Granite being intrusive.

Distribution.—The System makes in Prieska a regular belt running parallel to and west of the Doornberg Range, bounded on both sides by intrusive granite mostly and striking north-west to cross the Orange River above Upington. It forms a compound syncline or synclinorium, greatly folded, sometimes isoclinally, with the presumed lowest or Marydale beds on the two sides of the south-eastern section and with the uppermost division resting upon and embraced by the quartzite group in the heart of the broad, expanded section traversed by the Orange River.

Lying in the gneiss to the west are roughly parallel strips of extremely altered beds, for example just west of Kenhardt, trace-

[1] G. W. Stow, *Q.J.G.S.*, 1874, xxx, 581 ; Rogers and Schwarz, *Ann. Rep. G.C. for* 1899, 65 ; Rogers and du Toit, *ibid. for* 1908, 9 ; *ibid. for* 1900, 8 ; Rogers, *T.G.S.S.A.*, 1910, xiii, 93 ; T. W. Gevers, *Union S.A.G.S.*, 1937, Mem. 31 ; C. B. Coetzee, *T.G.S.S.A.*, 1942, 167.

able from near Pofadder through Pella into the great bend of the Orange with north-west strike. They reappear in the "horst" of the Great Karas (Kharas) Mountain with similar trend.

(a) *The Marydale Beds.*—Where least altered they are mainly lavas (mostly basic), together with tuffs, slatey rocks, and occasionally quartzite, arkose, quartz-magnetite schist (banded ironstone), and limestone, the entire series being perhaps a few thousand feet thick. They have been converted by the gneiss or much younger granite into crystalline granulites, schists, and paragneisses, the true nature of which has only been elucidated through less metamorphosed intermediate kinds. Some fairly fresh lavas occur in the Richtersveld.

From the village of Marydale down to Stuurman's Puts they form a belt dipping below the Kaaien quartzites; also at Blaauw Puts to the north. What has been taken for their basal development consists of arkoses and grits followed by cleaved lavas, represented at Zoet Vlei due south of Prieska. In this locality the rocks are least altered, but followed towards the north and west the basic types show progressively greater metamorphism, which reaches its maximum in the strips isolated in the gneiss to the west of Marydale. Just as with the greenstones of Rhodesia so they pass through green schistose epidiorites and dark hornblende schists into black crystalline granulites, the extreme types of the last-named containing hornblende, bluish pyroxene, labradorite-feldspar, and usually garnet. The amygdales are frequently well preserved, though sometimes much drawn out, and are composed of quartz with a little feldspar and epidote. The less abundant siliceous sediments in the group have been changed to pale granulites rich in quartz, with subordinate feldspar and hornblende and, when in close proximity to the intrusive granite, may contain garnet, sillimanite, staurolite, and cyanite. The magnetite-quartz rocks—along with serpentine—appear at intervals on the eastern side of the main belt associated with the above types and are closely folded. Like the Kraaipan ironstones they may contain actinolite or cummingtonite, but not crocidolite as in the Griquatown ironstones not so far away.

Limestones also occur intercalated in the acid and basic granulites, thin as a rule in the east, but thicker at Blaauw Puts north of Marydale and present in broad belts isolated in the gneiss at Mottels River and Vyf Beker south and north of Kenhardt respectively. They are white and crystalline and often charged with contact minerals such as garnet, diopside, olivine, scapolite, epidote, etc.

(b) *The Kaaien Beds.*—This predominantly quartzose formation builds the low north-westerly trending chains of the sandy

"Kaaienbult" to the west of the Doornberg known as the Brakbosch Poort Hills, also the nearly northerly-directed Buchu Berg and Roode Zand Mountains to the south-east and north-west of Kheis respectively. Beyond rises the Scheurberg, while outcrops are seen about Kuie Pan west of the Korannaberg and on the Kuruman River. The thickness must be a few thousands of feet, though hard to measure. The rocks consist of intensely hard, fine-grained, white but sometimes faintly greenish quartzites together with subordinate silvery mica schists. Conglomerates have only been recorded from the Richtersveld, where the Kaaien beds form the Rosyntjiesbos Mountains.[1]

Patches of recrystallised quartzites build chains between Pella and Steinkopf, a persistent band in the Springbok-O'Okiep area having formerly been regarded as a broad quartz vein. Granitisation may have made such strata all but indistinguishable from ortho-gneisses. Certain bands have been converted into pale grey or speckled granulites containing mica, hornblende, or contact minerals. Garnet-sillimanite-quartz schists are common in the strips in the gneiss west of the main belt and also on the Lower Molopo and near Langklip Station, and corundum-sillimanite gneiss at Steinkopf (Gevers). (See p. 64.)

(c) *The Wilgenhout Drift Beds.*[2]—These are confined to an area on the Orange River almost midway between Kheis and Upington, but in the section between Groot Drink and Karos are overlain by the Koras Series. Although much folded and sheared and traversed by some faults, they are seen in several places definitely to overlie and apparently to be conformable with the Kaaien beds. The general structure of the tract is that of a syncline faulted along its axis, and the thickness of the strata involved must be several thousands of feet.

They consist of sheared green diabasic lavas, breccias, and slates (probably largely sheared tuffs), but there are also quartz porphyries (probably lavas), crystalline limestones, green and red quartzites, and conglomerates (with quartzite and quartz schist pebbles). While greatly sheared, the beds are otherwise not much altered and do not exhibit the high degree of metamorphism of the Marydale beds, despite the fact that the granite and gneiss of the region is *intrusive*, three masses of gneiss penetrating the formation on Stofgat and Karos, the largest measuring 3 miles in length and half that in breadth. In Namaqualand their presumed equivalent, much altered by granitic matter, extends in a sinuous belt along the left of the Orange past Vioolsdrift.

[1] P. G. Söhnge and J. de Villiers, *T.G.S.S.A.*, 1947, xlix, 263.
[2] A. W. Rogers, *Ann. Rep. G.C. for* 1907, 35-42; *ibid. for* 1909, 50.

(3) *The Gariep System.*[1] Based on the native name for the " Orange River," this term has been applied to a thick assemblage in the Richtersveld that extends for unknown distances southwards as well as north-westwards into South-West Africa, its continuity broken in the middle by the Kuboos batholith. Because of folding and strike-faulting its relationships are not easily made out, but it is penetrated by the grey gneiss of the region (and by later granites) and appears to be younger than the Kheis System, while older than the Numees Series (Fig. 10), and, by inference, than the Stinkfontein Series.

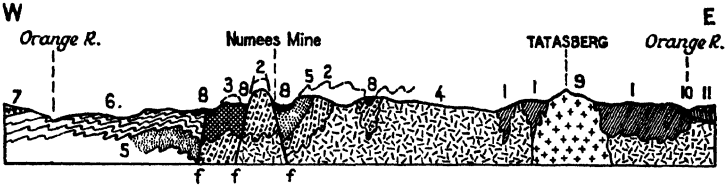


FIG. 10.—Section, 40 miles long, through the Richtersveld, Namaqualand (*adapted from* P. G. Söhnge and J. de Villiers). 1, Marydale; 2, Kaaien; 3, Gariep System; 4, Grey Gneiss; 5, Stinkfontein; 6, Kaigas; 7, Grootderm; 8, Numees; 9, Tatasberg Granite; 10, Nama System; 11, Dwyka; f, Fault.

Including arkoses, schists, marbles, and some quartzites and tillite, it has provisionally been compared with the Damara System farther north. Certain strata in Van Rhynsdorp have been tentatively referred to the middle division of this system —the Hilda Series—by Lamont.

E. South-West Africa and Kalahari[2]

Here one discovers vast areas composed of gneisses, schists, and metamorphosed sediments of an almost bewildering variety of lithological types, extraordinarily well exposed for the most part. The principal belts of altered and highly folded sediments are clearly recognisable as such, but along their margins there is a wealth of " mixed rocks," in the form of isolated strips included

[1] P. G. Söhnge and J. de Villiers, *ibid.*

[2] See particularly P. A. Wagner, *Union S.A.G.S.*, 1916, Mem. 7; E. Krenkel, *Geologie Afrikas*, 1928, ii, 645-717; T. W. Gevers and H. F. Frommurze, *T.G.S.S.A.*, 1929, xxxii, 31; T. W. Gevers, *Neu. Jahr. f. Min.*, B-Bd, 1934, 72, B. 399, and *T.G.S.S.A.*, 1934, xxxvii, 221; W. P. de Kock, *The Geology of Western Rehoboth, Dep. Min. S.W.A.*, 1934, Mem. 1.

in the gneiss of the kind to which reference has been made elsewhere, often interleaved to an extreme degree with the igneous rocks (Plate II).

In the Central Region, where alone detailed mapping has been done, enormous thicknesses of strata are represented belonging to at least two, and probably three, systems into which the main granite of the Territory is intrusive. Away from this type area the correlation of the various tracts of much altered formations becomes uncertain.

(1) Along the southern side of the Khomas Highlands with south-westerly strike, and expanding in that direction, appear the earliest rocks known, the *Abbabis System*—quartzites, phyllites, marbles and mica schists (marked 22A on Geological Map)—pierced by pre-Damara gneiss and pegmatite.

(2) *The Damara System.*—This reposes unconformably upon (1), probably exceeds 35,000 feet in thickness, builds up the Khomas and Windhoek Highlands and occupies wide areas in Damaraland between Karibib and Swakopmund as well as in the region farther to the north. The strata are repeatedly folded along axes trending mostly north-east to south-west with local overturning and much intrusion of granite and gneiss. From relics in the coastal strip their course would seem to run in a regular arc down the shore to Lüderitz and then south-eastwards to join with that of the Gariep System.

(*a*) The *Lowest* or *Quartzite Series* consists mainly of massive pale to reddish quartzites giving rise to lofty ranges to the south of Windhoek that extend eastwards into the Kalahari, swelling out greatly in places though poorly developed to the north of the Khan River. Similar beds are represented farther to the north near Grootfontein, among which are quartz conglomerates, and again not far from the Okavango River in the Tsodilo Mountain. A basal conglomerate with pebbles of quartz, quartzite, granite, gneiss, etc., is locally present to the south and south-west of Windhoek.

(*b*) The succeeding *Marble Series* is best developed in the Karibib and Omaruru districts, where it builds high ranges, being made up predominantly of crystalline limestones and dolomites with intercalations of phyllites, biotite schists, and amphibolites that stretch regularly for miles.

The marbles are of various colours, white, grey, yellow, and black, the finer-grained varieties making a good ornamental material and being quarried for that purpose at several places, *e.g.* Karibib. Where altered by the granite, the marbles become coarsely crystalline calc-silicate rocks in which the following minerals may be developed—tremolite, hornblende, wollastonite, scapolite, diopside, chondrodite, graphite, etc. The limestones may pass laterally into graphitic schists.

With north-easterly strike, far out in the Kalahari on the 21st meridian, metamorphosed dolomites form the Aha Mountains (Passarge), in which is situated Drotsky's Cave (Wayland), and crop out again on the Okavango River at Mohembo.

(*c*) The *Chuos Tillite*[1] is variably developed on the south-eastern side of the Highlands—to the south of Windhoek and north of Rehoboth—though more continuous and thicker on the north-western side, attaining a figure of 1500 feet at the Chuos Mountain south-west of Karibib. The material ranges from hard greenish-black dense tillite through soft contorted biotite schists with inclusions into pebbly limestones. Intercalations of grit, quartzite, and schist may occur, while the whole is in places overlain by banded sediments closely simulating glacial seasonal deposits. The transported inclusions are mainly of quartzite and often well facetted.

In the north-west the glacials intervene between the Quartzite and the Marble Series, but in the south they occupy the upper part of the latter, a relation which is due to a lateral change in facies of the enclosing strata. The area concerned is fully 20,000 square miles in extent, and a long period of glacial activity is indicated.

(*d*) The *Khomas* or *Schist Series* occupies the axis of the structural trough and consists of a huge thickness of biotite and muscovite schists with bands of chlorite, amphibole, and garnet schists and subordinate quartzites, grits, greywackés, and marbles, well seen in the lofty hills around Windhoek. Where invaded by the gneiss, contact minerals such as staurolite, andalusite, cordierite, cyanite, and garnet have been developed.

The greater part of the Kaokoveld is made up of rocks very similar to those in the centre and south. Kuntz found there a lower division consisting of amphibolite, chlorite schist, and mica schist, and an upper one in which phyllites, quartzites, and quartzitic sandstones predominate; while Beetz has described the several belts of similar

[1] T. W. Gevers, *T.G.S.S.A.*, 1931, xxxiv, 1; W. P. de Kock and T. W. Gevers, *ibid.*, 1932, xxxv, 115; W. P. de Kock, *ibid.*, 1934, 44.

highly altered strata along the Lower Cunene that pass northwards into Angola.

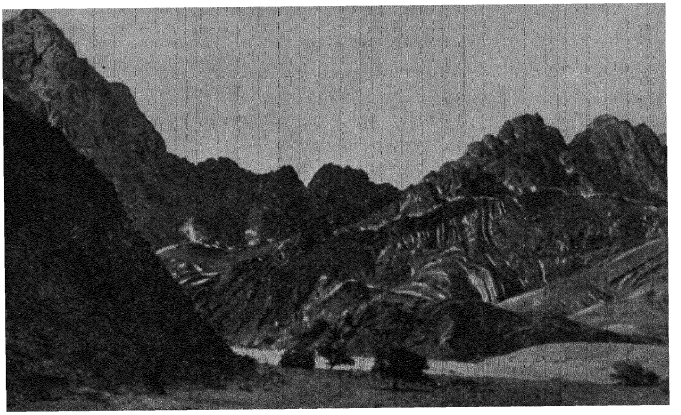


FIG. 11.—Bare Ranges of Schistose Rocks of the Damara System near the Khan Mine east of Swakopmund, a scene typical of this arid region.

Correlation within South Africa.—Comparison of these provokingly numerous ancient groups is greatly hampered by the large distances between such areas and the fact that correlations have to be based on lithological grounds with the likelihood of changes of facies and local unconformities—perhaps masked by tectonic disturbances. These oldest formations display, moreover, striking repetitions of such widespread types as greenstones, greywackés, limestones, etc., in a more or less altered condition. Having been found on various widely spaced horizons, such peculiar types as banded ironstones, pillow-lavas, and tillites have lost much of their value. The most promising solution would seem to lie in the determination of their absolute ages through radioactive or other atomic methods.

Whereas the so-called " Old Granite " is intrusive into each of the earlier assemblages, and thus forms a helpful criterion of age, more than one such period of plutonic intrusion happens to be included in that term, while the discrimination of still later granites may prove difficult in practice. A good example is the Lower and Upper Pongola beds, said to be penetrated by " Old Granite " in Swaziland, though reminiscent of the Witwatersrand beds, and indeed described in that chapter.

PROVISIONAL CORRELATION OF THE PRIMITIVE SYSTEMS

South-West Africa		Prieska	Bechuanaland and Kalahari	Southern Natal	Zululand	Barberton	Southern Rhodesia	Portuguese East Africa
North	South and Namaqualand							
PRINCIPAL INTRUSION OF THE OLDER GRANITES								
Damara: Khomas Marble Quartzite	Gariep		Dolomite			Moodies	Shamvaian: Upper / Lower	Mbeza and Frontier (?)
							Bulawayan: Greenstones, etc.	Greenstones
					Nondweni	Fig Tree		
Abbabis	Kheis: Wilgenhout Drift, Kaaien, Marydale		Kraaipan	Dolomite of the Marble Delta	Mfongosi / Tugela	Onverwacht	Sebakwian: Magnesian	

The wavy line indicates an Unconformity

The accompanying Table cannot therefore be much more than conjectural and must remain liable to progressive revision as new data are presented. The lower part of the Kheis System, the Marydale Series, finds a counterpart in the Kraaipan System, which helps to link the Cape formations with the older of those in the eastern Transvaal and with the Bulawayan of Rhodesia. Of the younger and dominantly sedimentary formations the Gariep recalls the Damara in the south-west, and the Moodies the Upper Pongola in the south-east, the two latter displaying certain similarities with the Shamvaian of Rhodesia, with which can tentatively be classed the Frontier Series.

Directing attention to extra-African formations the best parallel is displayed with India, our oldest schist-groups agreeing closely with the Dharwars of Mysore State and the Aravallis, while the younger Pongola, etc., are very like the Cuddapahs. Almost identical rock groups occur in Western Australia, while the United States can also show remarkably similar rocks and successions in the Keewatin and so-called Huronian.

CHAPTER IV

THE OLDER OR BASEMENT GRANITES AND GNEISSES

Economic Importance. Distribution. Batholithic Intrusion. Differentiation. North-Eastern Region. South-Eastern Region. Cape. South-West Africa. Charnockitic Rocks

Economic Importance.—This is insufficiently realised, for the bulk of the ore-deposits of South Africa are genetically connected with the Older Granites, occurring either as lodes within the latter or more commonly as veins and replacements within the Primitive Systems into which those rocks have been intruded. Indeed, practically all the gold produced outside the Witwatersrand has had such an origin.

Such being the case, the prospector tends to give particular attention to contact zones surrounding intrusive tongues and batholithic masses, and searches for places where the altered stratified formations have locally been shattered and become impregnated with ores through the agency of the formerly molten masses that fused their way upwards, sending forth dykes and veins into the roofing strata, and finally setting free heated solutions containing compounds of gold, copper, silver, zinc, arsenic, antimony, tin, etc. The detailed study of the various kinds of gold-bearing reefs in Rhodesia and eastern Transvaal, for example, is serving to indicate more and more the dependency of mineralisation at that remote epoch upon igneous intrusion—mainly of granite, quartz porphyry, and felsite.

The ores of tin, tantalum, and tungsten—and, of course, the mineral mica—are usually connected with pegmatites either in the granite or schist, while the ores of the other metals, of which gold and copper are the principal, are practically confined to quartzose veins or siliceous impregnations. In addition a number of gem stones are to be found in or closely connected with the granites, particularly in South-West Africa, for instance aquamarine, beryl, cordierite, rose quartz, and tourmaline.

Distribution.—Over a vast area there are exposed ancient granitic and gneissic rocks *intrusive* into the Primitive Systems,

though, could all the younger strata be stripped away, the entire extent of South Africa would doubtless show up as one expanse of crystalline rocks, mainly plutonic in character, divided into sections by the rather subordinate belts of the more ancient invaded formations—deep infolds for the most part. Some of these primitive formations even include *conglomerates carrying water-worn pebbles of granite* derived from still older bodies, not yet located.

The largest single region is constituted by Southern Rhodesia, continued eastwards into Portuguese Territory, southwards into Bechuanaland and across the Limpopo into the Transvaal, whence it stretches through the " Lowveld " of the eastern part of that Province and extends as a much broken belt through Swaziland, Zululand, and Natal.

On the western side of the continent lies another huge area proceeding southwards from Angola through the coastal regions of South-West Africa and Namaqualand to Van Rhynsdorp, with a tongue passing eastwards along the Orange River Valley to Prieska. Glimpses can be had in Bechuanaland, south-western Transvaal, about Parys and near Johannesburg of the basement, the persistence of which beneath the covering of younger strata is capable of proof at many points, *e.g.* in the heart of the Karroo, by fragments brought up from below in the kimberlite pipes.

The wearing down of this folded terrain, which thereby furnished much of the rock-waste out of which the later geological systems were built, has revealed the deeper-seated portions of its granitic interior and has shown a repetition of various features such as characterise the pre-Cambrian complexes of other parts of the globe and are of a kind which would almost suggest a world-wide dissolution of the earth's crust and the envelopment of the fragments by acid magma making its way up from below.

Descriptions have been published[1] of the granites and gneisses of certain parts of the country but, dealing very largely with the interior portions of the masses, they are not very illuminating from the petro-

[1] The accounts scattered through official and other papers have been summed up by Horwood and Wade for South Africa generally, *Geol. Mag.*, 1909, 455, 497, and 543; by Wagner for South-West Africa, *Union S.A.G.S.*, Mem. 7, 1916; by Holmes for the adjacent Moçambique Territory, *Q.J.G.S.*, 1918, lxxiv, 31; by Willemse for the Pretoria-Johannesburg area, *T.G.S.S.A.*, 1934, xxxvi, 1, and Vredefort area, *T.G.S.S.A.*, 1938, xl, 43; by T. W. Gevers, *T.G.S.S.A.*, 1937, xxxix, 331, and *Union S.A.G.S.*, 1937, Mem. 31, by M. Mathias, *T.G.S.S.A.*, 1941, xliii, 175, and by C. B. Coetzee, *T.G.S.S.A.*, 1942, xliv, 167, for Namaqualand. For Analyses see Grout, *Journ. Geol.*, 1935, xliii, 294.

genetic viewpoint. The study, on the other hand, of the marginal zones of the great intrusions and of the associated granulitic and schistose rocks has shed much light on the origin of the varied assemblage of foliated crystalline rocks comprehensively termed *gneisses*, embracing the two classes of the ortho- and para-gneisses, of igneous and sedimentary parentage respectively.

Batholithic Intrusion.—A few words to explain how granitic intrusion has been effected may be of some service. The evidence not only from South Africa but from many other parts of the world all goes to support the hypothesis of "stoping and assimilation," under which the magma, acid or basic to start with, attained its present position very largely by a process of replacement. In working its way upwards, it forcibly wedged off blocks from the strata above, which sank through the magma to a zone of higher temperature and pressure and ultimately became partially or completely melted and incorporated with the igneous melt. Modern ideas are favouring more and more *molecular transformations in the solid rather than the liquid state.* Opinion seems general that *the dominant folding of the invaded strata must have been contemporaneous with such deep-seated granitic "intrusion,"* however that process was effected.

Aided by its volatile constituents the magma was able to insinuate itself along planes of stratification, jointing, or schistosity in the country rocks, whereby the latter became intensely altered, largely by a process of transfusion, the intrusive ultimately solidifying as BATHOLITHS—also called PLUTONS—accompanied by sheets, dykes, or veins of granite, pegmatite, and aplite. According to their size two principal types can be distinguished.[1]

(a) *Large Batholiths*, from 20-50 miles across with the invaded strata set roughly parallel to the margin, where they have been picked off layer by layer through *"lit-par-lit injection,"* and banded composite gneisses, para-gneisses, or migmatites produced by assimilation with streaks containing garnet, cyanite, sillimanite, etc., to indicate relics of sedimentary origin. Xenoliths are common and "roof-pendants" not unusual. The foliated varieties bordering the body produce rolling country, while the "core," which may consist of a somewhat younger and more massive or porphyritic type, tends to make ranges or hills.

[1] A. M. Macgregor, *Geol. Mag.*, 1932, 18.

(b) *Small Batholiths, Bosses, Stocks, and Cupolas*, presumably widening downwards, with margins usually sharp and often transgressive, showing a narrow aureole of metamorphism, few inclusions and few signs of assimilation. They are composed of rock of fairly uniform composition, or of two or more distinct types, such as granite, quartz porphyry, or felsite, and are sometimes coarse-grained. Representing not infrequently the product from the still liquid interior of a subjacent Large Batholith, they may pierce the granite-gneiss of the latter as well as the formation invaded by it, and are commonly attended by still later pegmatite and aplite veins. While an anticlinal position is most frequent, a synclinal situation is possible, as shown in the area covered by Fig. 4. Such bodies are generally massive, non-foliated, and tend to make tors or spikes.

Differentiation.—Batholithic intrusion seems everywhere to have occupied a long period and to have occurred generally in *several marked phases* with progressive differentiation towards a more acid and/or alkaline product, the earliest fraction showing most clearly the influence of assimilation. Willemse [1] has pointed this out, in addition to the fact that those of Southern Rhodesia contain an excess of magnesia over those of the Union (Analyses Nos. 6, 7, and 8), and that the Basement Granites of South Africa are chemically and mineralogically closer to the quartz diorites, tonalites, and granodiorites, with modal potash feldspar less than plagioclase, a conclusion also reached by Grout, and confirmed by Coetzee for the earlier phase in eastern Namaqualand. Hornblende is a rare constituent, though present in the (early) De Kaap granite of Barberton (Van Eeden). The later Basement Granites tend, however, to be acid and normal. It is difficult to make closer comparisons, since " Old Granites " of several ages are now definitely known in each of the widely parted principal regions.

In view of the widespread evidence for appreciable assimilation, the writer feels that but few of the earlier basement granites could have escaped contamination and that even some of the later phases might have suffered as well. Indeed, a tabulation of the length-breadth ratios of the zircons in the Springbok granite has suggested a sedimentary origin (Coetzee). The most resistant strata are quartzites, which might explain the high acidity of the latest phases. If such be even partially true, then the de-

[1] *T.G.S.S.A.*, 1938, xl, 94-101.

ductions from petrographical analysis must lose much of their force.

The North-Eastern Region.—Rhodesia, with its enormous stretches of exposed granite and gneiss, continued into Portuguese East Africa and the Transvaal, constitutes an excellent field for the study of the relations of the plutonic masses to the schists and greenstones.

The *Large Batholiths* range from 20 to over 50 miles in width, gaining in size towards the east, and are separated by relatively narrow and winding belts of schist (p. 30),[1] and display the general characters stated above. Of such the great Umtali batholith is a fine example, with its massive core forming the bold hills surrounding that town, while the curious bare peaks, such as Mount Mapembi near Odzi Siding, and the Vumba, Gorungwé and others near Chimoio, recall the extraordinary landscape observed by Holmes in Moçambique. For the Bulawayo area Amm [2] has reported an earlier gneiss-granite followed by a porphyritic granite—as in the Matopos—and that by a fine-grained and sometimes porphyritic one. On north, south, and east, and extending far into Portuguese Territory,[3] are enormous developments of composite gneisses abundantly veined with pegmatite and aplite, but grading here and there into recognisable sediments. Graphitic gneiss occurs in the Umpunga district.

Of the *Small Batholiths* certain are younger than the main complex, for instance those in the Impali Valley to the west of Selukwe, in the Bembesi Valley and in the Belingwe, Insiza, and Gwanda districts.

The width of any " contact-zone " of metamorphosed rocks veined by granitic matter is variable and its limits sometimes difficult to define in the field. For example, the Heany granite mass east of Bulawayo is sharply bounded on its northern, but indefinite on its southern, side. Such a belt would be narrower and sharper where the schists made a deep infold into the crystallines, *e.g.* at Umtali, whereas the width of composite gneiss could be considerable where the batholith lay close beneath the surface.

[1] F. P. Mennell, *Q.J.G.S.*, 1910, lxvi, 353 ; A. M. Macgregor, *Geol. Mag.*, 1932, 18 ; R. Tyndale-Biscoe, *S. Rhod. G.S.*, 1940, Bull. 36, 26-50.

[2] F. L. Amm, *S. Rhod. G.S.*, 1940, Bull. 35, 48-66.

[3] E. O. Thiele and R. C. Wilson, *G.J.*, 1915, xlv, 16 ; E. O. Teale (Thiele), *T.G.S.S.A.*, 1923, xxvi, 103 ; C. F. de Andrade, *Esboço Geol. Prov. Moçam.*, 1929, ch. iv.

Of granite *stocks* few have been described from Portuguese Territory. The great rugged Gorongoza mass north-east of Beira, which projects about 4000 feet above the surrounding country, is a medium-grained pink and red hornblende granite intrusive into the gneiss and is associated with granophyres. In Rhodesia several examples lie just north and east of Salisbury. The Hillside intrusion just outside Bulawayo, like some near Gatooma, is in part syenitic and of a somewhat alkalic type with microline, oligoclase, hornblende, and ægirine-augite; close by are quartz porphyry bodies (Fig. 4). Six stocks in the Gwanda area are composed of adamellite, monzonite, and quartz diorite (Tyndale-Biscoe). Of metallogenic importance is the multiple quartz diorite stock of Penhalonga, Umtali.[1]

The Quartz Porphyries and Felsites are abundant in Rhodesia and of importance in being so frequently associated with mineral deposits. They are well developed about Salisbury and Selukwe, but particularly around Gatooma.[2]

Ranging from massive quartz porphyries to fine-grained felsites, which are frequently banded, they have in places been intensely sheared and converted into "porphyroids," or even into pale highly fissile quartz-sericite schists, notably around Mount Darwin and Gatooma; ultra-acid varieties, almost indistinguishable in hand specimens from quartzites, are also to be found as in the Enterprise mining field near Salisbury. There is a general poverty in ferro-magnesian minerals, though soda-lime feldspars are commonly present (see Analysis No. 10).

Their form is variable: there are large homogeneous masses, chiefly porphyries, greater areas made up of various types of felsites and small dyke-like occurrences, but they all have a rough parallelism with the prevailing strike of the rocks, conforming in a general way with the edges of the dominating granitic bodies. While in the majority of cases they appear to be intrusive into the schists and greenstones, their relationship to the granite is rarely determinable, mainly owing to the lack of exposed junctions. In the Enterprise mineral belt near Salisbury and near Battlefields Station they are older than the latter, but in a number of other instances they are certainly offshoots from the granite batholiths or of slightly later date than the latter. Research has shown that many of the rocks supposed to be felsites are actually

[1] *S. Rhod. G.S.*, 1937, Bull. 32, 58.

[2] *S. Rhod. G.S.*, Bull. 5, 1918; Bull. 7, 1920; Short Report, 12, 1923; Bull. 17, 1930.

fragmental—feldspathic grits or crystal tuffs mainly—in view of which many occurrences will require re-examination.

The felsites—especially the finer compact types—have in places undergone remarkable transformations involving carbonisation, leaching, silicification and finally impregnation with ferruginous matter. The end-products consist of ferruginous banded cherts or jaspers practically identical outwardly with the banded cherty ironstones of presumed sedimentary origin in the greenstone schists. Such secondary changes have not proceeded below permanent water-level. "Banded Ironstones" of this kind are typically developed at Gatooma [1] or at the Mazoe Dam. These remarkably altered types are of economic as well as of scientific interest in that they so frequently form the country rock of certain classes of gold reefs. They consequently recall similar rocks abundantly found in the various goldfields of Western Australia.

The South-Eastern Region.—Granite and various types of gneiss build the northern and eastern parts of the Transvaal and extend through Swaziland into Natal, the continuity of outcrop being interrupted by belts of older formations such as at Woodbush, Murchison Range, Barberton, Piet Retief, Vryheid, and the Tugela Valley. All of these belts have been invaded by the granitic magma with the production of banded and composite gneisses just as in Rhodesia.

The granite or granite-porphyry type is again important topographically, as exemplified by the Palabora mass in the Murchison Range, or in the bare domes north-west of Messina known as the two "Plaatjes." Non-foliated or feebly banded varieties separate the Barberton schist belt from that of Piet Retief and the latter from the schists of the Tugela; another such area occupies the south of Natal.

Recent studies have shown for more than one area several intrusive phases of the "Old Granite," the earliest the most *basic*. Thus, just west of Barberton appears the De Kaap Granite with intrusive contact against the Jamestown Igneous Complex, a pale greenish quartz-hornblende diorite with 65 per cent. of silica, followed by the Nelspruit Granite, well seen to the north, a grey gneissose granodiorite with biotite and 69 per cent. of silica, and that by the M'pagene Granite of Krokodilpoort, a massive coarse reddish granite with albite and 71·5 per cent. of silica (van Eeden). A similar sequence is present in the Murchison Range, and may be widespread.

[1] A. E. V. Zealley, *T.G.S.S.A.*, 1918, xxi, 43.

Around Bandolier Kop and near Leydsdorp corundum has been developed in granitic injections into serpentine and amphibolite (see p. 511). In the Tugela Valley serpentine thus invaded has been converted into talc by transfer of silica from the magma. Not improbably the majority of the occurrences of talc schist in the gneiss elsewhere have been formed in such a manner. The large Palabora or Palaboroa mass east of Leydsdorp consists principally of even-grained " ball granite " intrusive into the gneisses, which are in places seamed by pegmatites, the source of the Transvaal's mica output. At Loole or Lulu Kop [1] a patch of carbonate rocks a few miles across has been enveloped by this granite and converted into crystalline limestone and coarse pyroxenites rich in apatite, phlogopite, and that valuable golden-coloured derivative therefrom—*vermiculite*.[2] The granite around this mass is pierced by numerous plugs and dykes of syenite.

Remarkable replacements of dolomites by granitic matter, as well as other curious types, have been described by Söhnge from the Messina area.[3]

Coarse pinkish granite bulks largely in the oval inlier to the north of Johannesburg, but on the south-east and south-west it has invaded and veined hornblende schists and serpentines with the production on a small scale of dioritic types. The bosses at Heidelberg, Parys, and Klerksdorp are of a similar type, mainly biotite granite or granodiorite. A reddish granite intrudes the Pongola System near Kubuta in Swaziland.

The Cape Province.—Between Prieska and the Atlantic, stretching across Bushmanland and the Orange River into South-West Africa, gneisses and granites are widely developed, intrusive solely into the Kheis rocks by which their petrological characters, foliation, etc., have become greatly influenced. The more variable and commonly migmatic varieties flank belts of Kheis beds and are traceable as sinuous streaks or schlieren with general north-west or west-north-west trend that mark deep infolds or roof-pendants. Foliation-dips in such materials are usually moderate and may run regularly for long distances.

" Contamination " of the magma through absorption of sedimentary matter is betrayed by the occasional presence of contact minerals such as garnet, sillimanite, and cordierite, as in the conspicuous black knob south of the railway bridge at Upington, composed of a coarse rock showing brown crystals of cordierite up to an inch in length. Corun-

[1] A. L. Hall, *T.G.S.S.A.*, xv, 4 and 18; *Union S.A.G.S.*, Mems. 6 and 13; S. J. Shand, *T.G.S.S.A.*, 1932, xxxiv, 81; A. L. du Toit, *ibid.*, 107.

[2] C. M. Schwellnus, *Union S.A.G.S.*, Bull. 11, 1938.

[3] P. G. Söhnge, *Union S.A.G.S.*, Mem. 40, 1945, 34, 62.

dum is found in barrel-shaped crystals in a micaceous gneiss east of Steinkopf. About Springbok, Concordia, and Nababeep there is much pale sillimanite gneiss with a gently inclined foliation due to bands richer in sillimanite, biotite, or feldspar. Such zones run roughly east-west in the Kamiesberg area. The prevailing rock [1] is a grey biotite gneiss, often garnetiferous—conspicuously so in the south. In that district, too, occur the numerically abundant suite of copper-bearing intrusions of somewhat later date, referred to on p. 508.

For eastern Namaqualand the work of Gevers [2] and others has disclosed several fairly distinct, though over-lapping, intrusive phases progressing from basic to highly acid, each phase penetrating the earlier one :—

(1) The earliest is a granodiorite with local passage into migmatites and grading into or cut by a fairly coarse biotite or biotite-hornblende granite—in part gneissose—associated with porphyritic and micro-crystalline grey varieties.

(2) The Main gneiss-granite is a pale massive rock with some biotite tending to form domes, as to the east of Steinkopf, and also making " cores " in (1).

(3) Red or reddish-yellow aplitic granite and granite-porphyry having bluish quartzes and tending to form sheet- or dyke-like bodies.

(4) Pegmatites, largely marginal or exterior, superbly developed in the basal part of (1) within a belt 150 miles long and 12-15 miles wide running westwards from Goodhouse, as lenticular bodies trending north-west, in places hundreds of yards wide and making a veritable network, as in the Henkries Valley. In them occurs a profusion of characteristic minerals such as tourmaline, lepidolite, spodumene, beryl, and more particularly wolframite, scheelite, columbite, tantalite, and ores of bismuth and uranium—essentially where hydrothermal alteration has taken place and " differentiated quartz " has been produced.

South-West Africa.—As stated earlier, the Basement Complex forms the Atlantic coast-belt to a width in the north of about 120 miles, extending eastwards to double that distance in the broad tongue between Otavi and Okahandja, thereafter contracting towards the south with a considerable enlargement through the Warmbad district. In the unrivalled bare exposures

[1] A. W. Rogers, *Union S.A.G.S. Rep. for* 1912, 125.

[2] T. W. Gevers, *Union S.A.G.S.*, 1937, Mem. 31 ; *T.G.S.S.A.*, 1937, xxxix, 331 ; C. B. Coetzee, *T.G.S.S.A.*, 1942, xliv, 167 ; M. Mathias, *T.G.S.S.A.*, 1941, xliii, 175.

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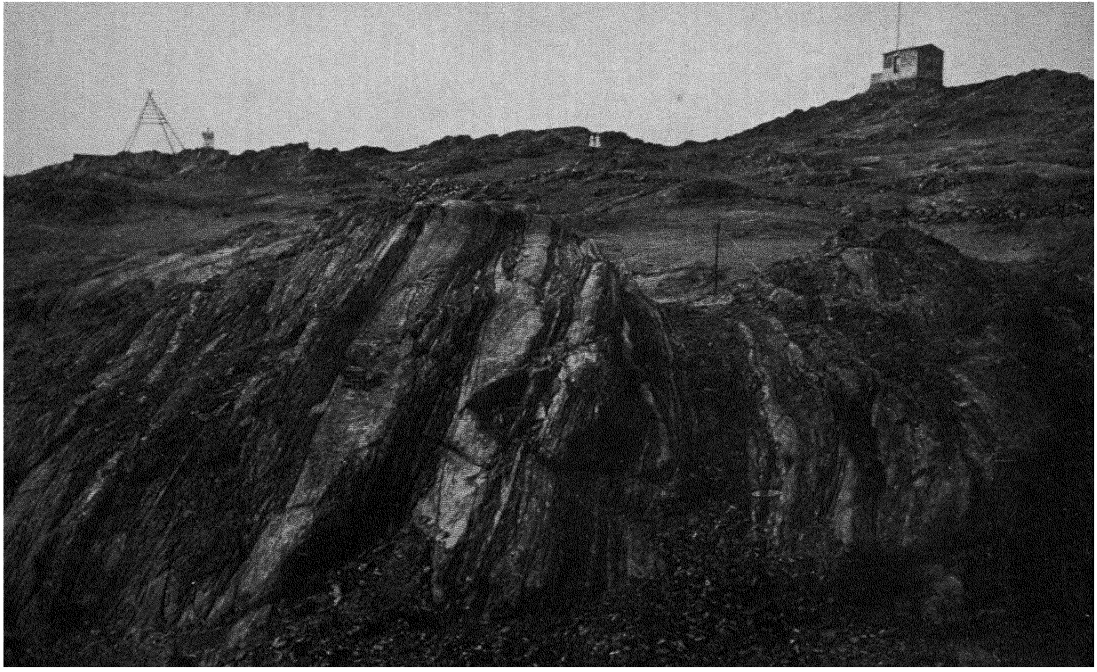

Mixed Rocks—biotite schists injected by granite and aplite, Diamantberg, Lüderitz.

PLATE II

throughout the arid portions of this fascinating country the relationships of the multitude of types concerned are splendidly displayed and variations in composition, in texture, and in age within this vast complex can be studied in minute detail (Plate II and Fig. 11).

As elsewhere, the homogeneous granites build up the important hills or ranges, *e.g.* the Aus-Kubub, Macdonald and Somerset Mountains in the south, and give rise locally to elevations of the "Inselberg" type. Biotite varieties predominate and are often porphyritic; garnet and epidote are frequent constituents. A huge area is formed of gneisses of various kinds with *mixed rocks* forming no small proportion thereof, while at least *three* distinct groups of granitic intrusion are found in them earlier than the Nama System; aplite, pegmatite, and quartz veins are abundant in all these rocks, as well as dykes of porphyry and porphyrite.

Beetz,[1] describing the phases of granite intrusion in the region of Aus, states that the earliest is a granite rich in greenish-white plagioclase, which has invaded the gneisses and has suffered much crushing. The second is a grey granite forming small stocks near Lüderitz and the main granite-gneiss range at Aus. The third is an acid, equigranular, often aplitic granite, sometimes greyish, but generally reddish. It cuts the older types at Aus and is met with also in the Kubub and Klinghardt Mountains, at Kunjas, etc.

In the central region a pre-Damara gneiss has been found by de Kock in Rehoboth as well as the universal post-Damara gneisses, together with a subsequent porphyritic alkali-granite (the Salem Granite)—grey in the Karibib-Swakop area and reddish in Otjimboyo, Windhoek, and Rehoboth—followed by "normal" granites and by pegmatites, etc. The Salem Granite is remarkably concordant within the highly-folded strata and, according to Gevers, seldom breaks across the strike. Pegmatites and pegmatitic quartz-veins are abundant in Damaraland, where they carry tin, tantalite, and occasionally bornite, scheelite, and apatite as well as tourmaline.

Charnockitic Rocks.—Forming part of the basement at Port Edward in the extreme south of Natal is a body at least 6 miles long consisting of massive dark grey hypersthene-bearing types of (*a*) quartz diorite, granodiorite, and quartz-monzonite, and (*b*) granite (*charnockite*) (Analysis No. 9). There is much myrmekite, the feldspars being mostly oligoclase to andesine in (*a*) and largely microperthite in (*b*). Opalescent blue quartz and hornblende are common and garnet

[1] W. Beetz, *T.G.S.S.A.*, 1924, xxvii, 1.

occasional. Boundaries with the " Old Granite " are in some spots sharp and suggestive of intrusion by the latter ; in others gradational.[1]

These curious charnockitic types are thought to represent highly metamorphosed rocks that have experienced partial granitisation. Described for the first time for the Union, but believed to occur in eastern Rhodesia, they are practically confined to India, Western Australia, Madagascar, Moçambique, Uganda, and Antarctica, a matter of immense palæogeographical significance.

[1] T. W. Gevers and J. C. Dunne, *T.G.S.S.A.*, 1943, xlv, 183.

CHAPTER V

THE WITWATERSRAND SYSTEM

Historical. Tectonics. Witwatersrand. Heidelberg-Bethal. Klerksdorp-Wolmaransstad. Vredefort. Extensions. Subdivisions. Lower Division. Upper Division. Free State Gold Fields. Gold-bearing Reefs. Origin of the Gold. Picture of Banket Formation. Igneous Rocks. Pongola System.

Historical.—Although the discovery of gold in the rocks of the Witwatersrand in 1886 concentrated attention upon them, their true geological position and relationships remained nebulous for a surprisingly long time, being for quite a while obscured by unwarrantable correlation with the Pretoria beds or with the Table Mountain Series of the Cape.

The designation " Witwatersrand Beds " seems first to have been given by Penning in 1891, but was probably in general use much earlier. Right down to 1901, however, this name was restricted, following Molengraaff, to the Upper Division, the Lower being termed the Hospital Hill Series and paralleled with the formations in the Barberton Goldfields, today regarded as much older. This correlation was assisted by the fact that down to 1904 the Old Granite was usually considered to be intrusive in the Orange Grove Quartzites, and was furthered by Molengraaff's observations of intense contact metamorphism in undoubted Lower Witwatersrand beds in the Parys area. The latter has since received other explanation, while the granite on the Rand and neighbourhood has definitely been found to be *older* than the sediments.

By surface exposures, which become more scanty farther out, the strata have been traced to just beyond Greylingstad, the Rhenoster River in the Free State, Wolmaransstad and Ottosdal, with the Dominion Reef Series extending apparently into the Cape Province ; but extensive drilling and geophysical prospecting have proved the system to have a far wider distribution, namely westwards possibly into Lichtenburg, south-westwards to beyond Odendaalsrus, southwards to near Frankfort, and eastwards well towards Bethal, and it seems furthermore to be present in northern Rustenburg, while in the extreme south-east it is probably

represented by the Godwan and Insuzi Series.[1] Its relation to the succeeding Ventersdorp volcanics and sediments is so intimate that it is difficult to discuss those formations apart. Presuming that the lower part of the sedimentary group forming the base of the Ventersdorp is actually of Elsburg age, the range of the system becomes extended well beyond the borders of the Transvaal. It is, however, not yet definitely known in Rhodesia or South-West Africa.

Tectonics.—Deposited unconformably upon the Old Granite or upon schistose rocks, this formation was in places subjected to folding, faulting, and to considerable erosion before being covered up by the Ventersdorp System, as finely seen in Klerksdorp and in the Bezuidenhout Valley, Johannesburg. Over the Rand, Heidelberg, and Vredefort areas it experienced only steady subsidence. It was disturbed again during and just after Ventersdorp times and, following burial beneath the Transvaal System, partook in the flexuring and fracturing which the latter thereafter experienced and received a full share of the matter subsequently erupted—mostly diabase.

Its exposures have primarily been determined by the removal of the Transvaal System, and its strata hence appear for the most part along the major anticlines traversing those younger beds; consequently its outcrops tend to make belts running roughly parallel with those described by the Transvaal System (Fig. 12). In order to elucidate its behaviour beneath the latter, when attempting to prove concealed ground, it becomes necessary to disentangle the older from the younger set of foldings and also to estimate the depth of the erosion to which the beds were subjected *before* the Ventersdorp or the Black Reef Series covered them.

The Witwatersrand Area.—Dipping away from the *Old Granite* at fairly high angles towards the south—especially in the Central Rand—but flattening out in depth in this direction and passing beneath the Ventersdorp lavas, the strata of this type area build up the watershed between streams flowing northwards into the

[1] F. C. Truter, *T.G.S.S.A.*, 1950, lii, pp. lii-lv, separated the Dominion Reef Series from the Witswatersrand System, raising the status to that of a Dominion Reef System, with which he correlated the Insuzi (Lower Pongola) Series, the Godwan beds of the eastern Transvaal, certain lavas and sediments lying between Denilton and Groblersdal, and a belt of lavas and sediments north of Thabazimbi (Editor).

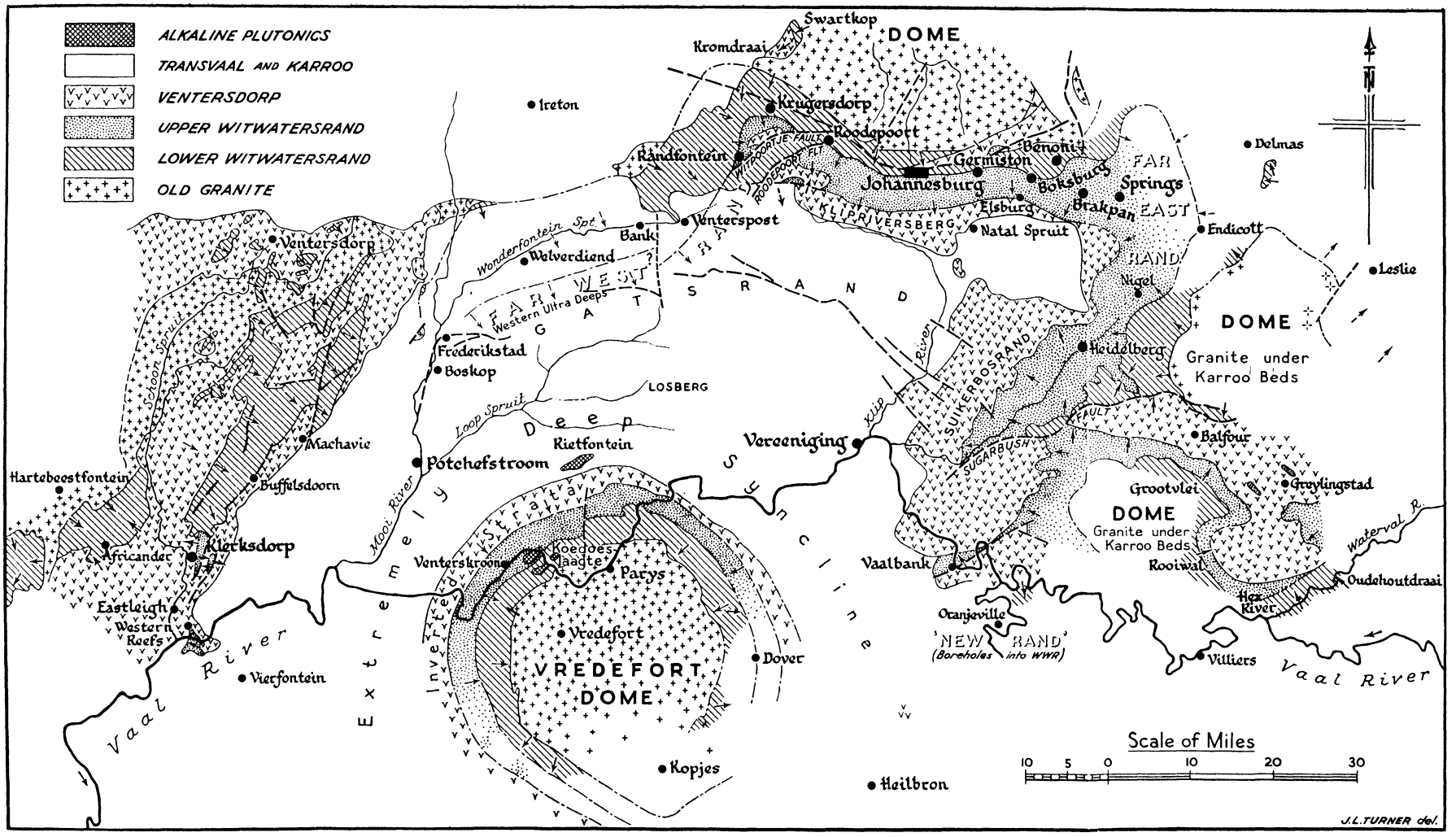

FIG. 12.—Map showing the distribution of the Witwatersrand and Ventersdorp Systems to the south of the Rand (reduced from the maps of the Geological Survey). Thick broken lines denote important faults; chain-dotted lines indicate approximate boundaries beneath the younger formations.

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Limpopo and southwards into the Vaal. This east-west ridge, which just fails to reach 6000 feet above sea-level, runs with only one break for 35 miles and was termed the " Witwatersrand " by the Boer settlers, apparently because of the whiteness of the quartzites along the northern escarpment. This belt, several miles in breadth, turns south-westwards at Krugersdorp and, after passing Randfontein, sinks beneath the Dolomite of the Wonderfontein Loop, its extension below this covering having been proved by deep borings to near Frederikstad with regular south-easterly dip, thereby constituting the Far West Rand or " West Wits areas," with the " Western Ultra-Deep Levels " on its dip-side. From over a stretch, only imperfectly known, pre-Ventersdorp erosion has removed much of the Upper Division.

The formation reappears in the anticlinal arch between Potchefstroom and Ventersdorp and is suspected to underlie the Dolomite north-west of the Krugersdorp-Ventersdorp road. This anticline really commences well to the north of Krugersdorp and is responsible for the detached strip of Witwatersand beds making the ridge known as Zwartkop, which are more contorted and seemingly thinner than on the Rand proper, dipping westwards beneath conglomeratic rocks belonging to the Ventersdorp System.

Throughout the West and Central Rand the beds are traversed by many strike faults, mainly of the overthrust type—mostly with horizontal shifts—several of them, such as the Rietfontein and the celebrated Witpoortje break, being of considerable displacement. The former brings up the Granite against southward-dipping supposed " Main-Bird " Series at the Rietfontein Mine north of Germiston. Unpublished evidence suggests, however, that this isolated block actually belongs to an upper stage of the Ventersdorp System. East of Boksburg the Witwatersrand beds flatten, pass directly below horizontal Coal Measures and thereafter beneath the Dolomite as well, the thickness of the latter being close on 1400 feet at the Daggafontein Mine. In this extensive concealed area—known as the East Rand—the Lower Division spreads to unknown distances ; but the Upper makes a relatively shallow subsidiary basin crossed by parallel folds of surprising amplitude (Fig. 21) with the Main Reef Zone curving round to the east and south to reappear at the Nigel Mine near Heidelberg.

In the *Main Basin*, stretching from the Far West to the Far East Rand, the reefs sink rapidly but regularly southwards to depths far beyond present-day limits of mining. It is only due

to the progressive flattening in dip and to the wonderfully low temperature-gradient underground that the reefs have been worked to distances of several miles from the outcrop and to depths in places of over a mile and a half vertically.

The Heidelberg-Greylingstad-Bethal Area.—South of the Nigel the belt made is a broad one, giving the full succession from the Granite on the east to the Ventersdorp lavas of the Suikerbosrand on the west. The beds are complexedly faulted and are also heavily injected with diabasic and noritic intrusions. The most important fracture is the Sugarbush Fault, which runs with an irregular course from the lower part of the Suikerbosrand River across to Fortuna; it has a maximum throw (to the south) of 16,000 feet, thereby duplicating the succession. Borings and geophysical surveys have shown that the Lower Division, resting on the Granite, extends north-eastwards from Heidelberg to Leslie and to Langverwacht No. 111 near Trichard at least,[1] with north-easterly dip at moderate angles beneath a thickening cover of Ventersdorp, Transvaal, and Karroo beds. No horizons higher than the Government Reef Series were, however, cut. An excellent marker has been the Contorted Bed. South of the Sugarbush break the beds are much concealed by Coal Measures in patches and wider areas, but have been bent into a dome, the granitic core of which lies wholly buried beneath the South Rand Coalfield. Around it the upper half of the system makes discontinuous and roughly concentric outcrops, passing beneath the lavas on the west, north, and east, to crop up again along anticlinal axes at Greylingstad and to the north thereof.

The lower beds are rarely exposed, the most important inliers occurring not far from the Vaal River on Hex River and Drie Fontein to the north-east of Villiers; but the south-western side of the dome has been extensively probed beneath a thick covering of Karroo by the numerous boreholes put down on both sides of the Wilge River in the Orange Free State, just above its junction with the Vaal, where the dip of the beds, much split up by diabase sills, is southwards—an area formerly referred to as the "New Rand."[2] To the west of this locality it is known that there exists a very deep syncline, which must cut off this area from the Vredefort "Dome."

[1] E. F. Fox, *T.G.S.S.A.*, 1940, xlii, 83.
[2] A. R. Sawyer, *Trans. Inst. Min. Eng.*, 1912, xliv, 4.

The Klerksdorp-Ventersdorp-Wolmaransstad Area.—This wide region includes important goldfields long known and worked,[1] but greatly expanded today. In the core of the anticline between Ventersdorp and Potchefstroom the Lower Division appears resting on the Old Granite, making a wide belt with south-westerly strike and south-easterly dip much broken and repeated by step-faulting and extensively concealed by the unconformably overlapping Ventersdorp volcanics (Fig. 12). As shown on Nel's map,[2] the structure is very complex. To the north-east these beds pass beneath the Dolomite; to the south-west they are traceable to across the Vaal River and continue underground to the Vredefort and Odendaalsrus areas. To the west—beyond the lengthy "Platberg Syncline" of Ventersdorp rocks—they reappear in the "Afrikander-Rietkuil Syncline," with a second area around Rhenosterspruit and inliers at Ottosdal far to the north, all overlapped by amygdaloidal lavas.

As proved by their various "markers," all the series of the *Lower Division* are represented. In the Basal or Dominion Reef Series[3] of volcanics and sediments west of Klerksdorp auriferous pebbly bands were long mined as the Dominion Reef on Rhenosterspruit, while conglomerates belonging to the Government Reef Series are worked at the Afrikander and Babrosco Mines on Rietkuil to the west and at Buffelsdoorn to the north-east. The Jeppestown Series, 2000-3000 feet thick, (accompanied by its amygdaloid) is more quartzitic here, with dark fine-grained types.[4]

Of the *Upper Division*, strata at least 1000 feet thick, following in normal position and thought to be the Main-Bird Series, project through the Ventersdorp lavas in two faulted strips at the town of Klerksdorp with the Ada May Reefs lying at 200-300 feet above their base. Their apparent upward continuation, a quartzitic group some 4000 feet thick, intersected between Klerksdorp and the Vaal River, includes peculiar gritty types with abundant fragments of various cherts, and carries in its upper part the densely-packed banket recently termed the "Vaal Reef," struck beneath Dolomite on Witkop and Zandpan. The persistent Gold Estates Reef group of quartzites, grits, and conglomerates, some 1700 feet thick, rests on the aforegoing with

[1] G. A. Denny, *The Klerksdorp Goldfields*, 1897, 1-247.
[2] *Union S.A.G.S.*, 1934.
[3] See foot-note on p. 68.
[4] P. F. W. Beetz, *T.G.S.S.A.*, 1936, xxxix, 223.

strong angular unconformity, as can very clearly be seen on the Klerksdorp Town Hill, described and figured by Jorissen.[1] These are usually accepted as representing part of the Elsburg Series. The big-pebble Gold Estates Reef, exploited at the town of Klerksdorp, has been proved not only beneath the Dolomite to the south-east but to the south across the Vaal River. In block-faulted ground at Western Reefs the higher bankets at the top are discordantly overlain by the Ventersdorp Contact Reef (p. 121).

The Vredefort Area.[2]—Here the Witwatersrand, together with the two succeeding systems, wraps around the upthrust and everted mass of the Parys Old Granite in a circle, of which nearly three-fourths of the circumference can be examined, the remainder on the south-east being concealed by Karroo beds (Fig. 33). The strata have been uptilted and mostly inverted, the quartzite groups giving rise to concentric chains of hills of remarkable regularity with, however, a considerable amount of faulting. The full succession from the Orange Grove Quartzites to the top of the Elsburg Series is represented, the subdivisions being thinner than on the Rand with the exception of the Elsburg, which is unusually thick—about 10,000 feet—on the north-western or overturned side, part of which anomaly must be due to tectonic causes. It is, moreover, markedly conglomeratic, some of the bands having formerly been worked, as on Rooderand, under the name of the Amazon Series. Drilling for reefs between Kopjes, Heilbron, and Edenville has been undertaken and Witwatersrand beds have been proved on Slootkraal and Brakdam.

As detailed in Chapter VIII, the Witwatersrand beds here display evidence of an intense metamorphism of a two-fold kind.

Extensions.—Apart from the important Odendaalrus area the following cases can be considered :

(*a*) Assuming an Elsburg age for certain quartzitic groups in apparently conformable position below Ventersdorp lavas in the south-western Transvaal and north-western Cape (p. 120), there are many places where conglomeratic bands present themselves for prospecting, for example near Schweizer Reneke or at Pokwani,

[1] E. Jorissen, *T.G.S.S.A.*, 1906, ix, 40.

[2] A. L. Hall and G. A. F. Molengraaff, *Kon. Akad. Wet. Amsterdam*, 1925, xxiv, 3 ; L. T. Nel, *Union S.A.G.S.*, " The Geology of the Country around Vredefort," 1927, 1-130.

near Taungs. The same will apply to the basal beds of the Zoetlief—or supposed Dominion Reef—Series.

(*b*) Appearing in north-western Rustenburg in a curving belt at least 40 miles long that crosses the Crocodile River just below Vliege Poort is a thick group of sediments resting on schists, though with sand-concealed base, dipping south-eastwards at moderate angles and overlapped by basic and acid volcanics, a formation originally regarded as of Ventersdorp age, though more probably Witwatersrand. Attaining a thickness of over 6000 feet on Kameelpoort and Buffelshoek, it comprises brownish quartzites, sandstones, and grits with thin conglomerates, certain of them auriferous, and occasional reddish shales and flagstones.

(*c*) It is thinly developed with similar relations on Uitkyk, 854, near Potgietersrust, including greenish quartzites containing chromiferous mica, and conglomerates with pebbles of banded ironstones and Old Granite (D.P. van Rooyen).

Subdivisions and Thickness.—The alternation of contrasting quartzitic and slaty groups, often possessed of distinctive lithological characters, has enabled the system to be rather minutely subdivided, which is fortunate in view of its great thickness and of its complexedly faulted nature wherever it is known. Certain thin bands known as " markers " have, for example, proved of immense value in deep drilling.

The order and thickness of the various zones have been firmly settled by the work of Mellor on the Rand, of Reinecke on the Far West Rand, of Rogers in Heidelberg, of Nel in Vredefort, and of Nel and Beetz in Ventersdorp and Klerksdorp, the amount of detailed information already gathered being immense.[1]

A two-fold division into UPPER and LOWER [2] follows naturally from the fact that there is a conspicuous alternation of siliceous and argillaceous bands in the inferior part of the system, whereas

[1] See the various contributions by E. T. Mellor, especially those on the Central Rand, *T.G.S.S.A.*, 1911, xiv, 24-42; 1911, xiv, 99-131; 1913, xvi, 1-32; 1915, xviii, 11-56; 1915, xviii, 57-71; *ibid., Union S.A.G.S. Rep. for* 1911, 33-60; *Ann. Rep. for* 1912, 29-66; also Geological Map of the Rand with explanation, 1917; A. W. Rogers, Geological Map of Heidelberg with explanation, 1922; L. T. Nel, *The Geology of the Country around Vredefort*, 1927; *The Geology of the Klerksdorp-Ventersdorp Area*, 1935; *The Witwatersrand System outside the Rand*, *P.G.S.S.A.*, 1934, xxxvi, p. xxiii; P. F. W. Beetz, *T.G.S.S.A.*, 1937, xxxix, 223.

[2] The habitual use of the terms " Lower " and " Upper Witwatersrand *System* " is much to be regretted.

the superior is predominantly quartzitic; moreover, the most important set of gold-bearing conglomerates usually makes its entry with this change of lithology. Although *no marked stratigraphical break* has been found at this horizon in the Rand-Heidelberg-Vredefort region, *a strong unconformity* is present within the Upper Division in the Klerksdorp and probably in the Odendaalsrus district, while to the north of the Central Rand there occurs a similar discordance beneath beds which may belong to the Elsburg Series.

The grouping is as follows :—

B. *Upper Division* . .	6. Kimberley-Elsburg Series. 5. Main-Bird Series.
A. *Lower Division* . .	4. Jeppestown Series. 3. Government Reef Series. 2. Hospital Hill Series. 1. Dominion Reef Series.

The maximum development—almost 25,000 feet, exclusive of igneous sills—is attained in the Central Rand (Fig. 13); and not only the whole assemblage but generally also each subdivision becomes thinner when traced in a south-easterly and also, though not so systematically, in a south-westerly direction, the striking exception being Group (6) in Vredefort (Fig. 14).

A. The Lower Division

No less than 15,000 feet thick in the Central Rand, there is a diminution to perhaps 13,000 feet in Klerksdorp, 11,000 feet in Vredefort, and 9000 feet in Heidelberg. Topographically the division displays a number of parallel or sub-parallel low ridges due to the out-cropping of the several quartzite zones, flanked by softer shaly beds. Usually the various members possess lithological characters distinctive enough to enable them to be identified over wide areas but, where the strata peep out only as small inliers through a covering of Coal Measures, it may become extremely difficult to determine their exact horizons. This applies more particularly to the members of the Jeppestown Series, say in a complicatedly faulted area such as Heidelberg.

Apart from the conversion of the arenaceous types into quartzites by the deposition of secondary silica and to the development of sericitic mica or chloritoid in the slaty types,

there has been no extreme metamorphism. A conspicuous exception is the Parys area, where the strata exhibit intense alteration, due in part to a subjacent igneous body (p. 198).

(1) **The Dominion Reef Series.**[1]—(*a*) In the Vredefort area, intervening between the Old Granite and the Orange Grove Quartzites, is a sheet of rather metamorphosed basic igneous rocks, absent on the east but swelling to 800 feet on the west and south-west, which from occasional amygdaloidal characters is regarded as a volcanic outburst ushering in the system.

(*b*) Comparison can be made with the similarly situated Dominion Reef Series of Klerksdorp—so named by Molengraaff — consisting of dense quartz porphyries, felsites and silicified rhyolites and cherty beds underlain by dark amygdaloidal lavas and those by a thin group of quartzose sediments, arkosic in places, carrying gold-bearing conglomerates at or above its base which constitute the *Dominion Reefs*.[2] Where sheared, such arkoses

[1] L. T. Nel, *Union S.A.G.S.*, 1927, Expl. Geol. Map, 30. See editorial footnote on p. 68.

[2] L. T. Nel, *ibid.*, 1935, Expl. Geol. Map, 37.

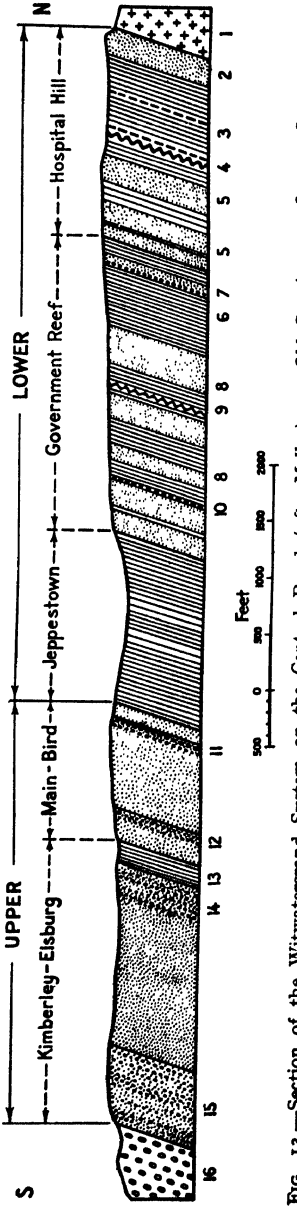


FIG. 13.—Section of the Witwatersrand System on the Central Rand (*after* Mellor). 1, Old Granite; 2, Orange Grove Quartzites; 3, Hospital Hill Shales; 4, Contorted Bed; 5, Hospital Hill Quartzites; 6, Promise Beds; 7, Promise Reef; 8, Coronation Beds; 9, Coronation or West Rand Shale; 10, Government Reef; 11, Main Reef; 12, Bird Reefs; 13, Kimberley Shales; 14, Kimberley Reefs; 15, Elsburg Reefs; 16, Ventersdorp Amygdaloid.

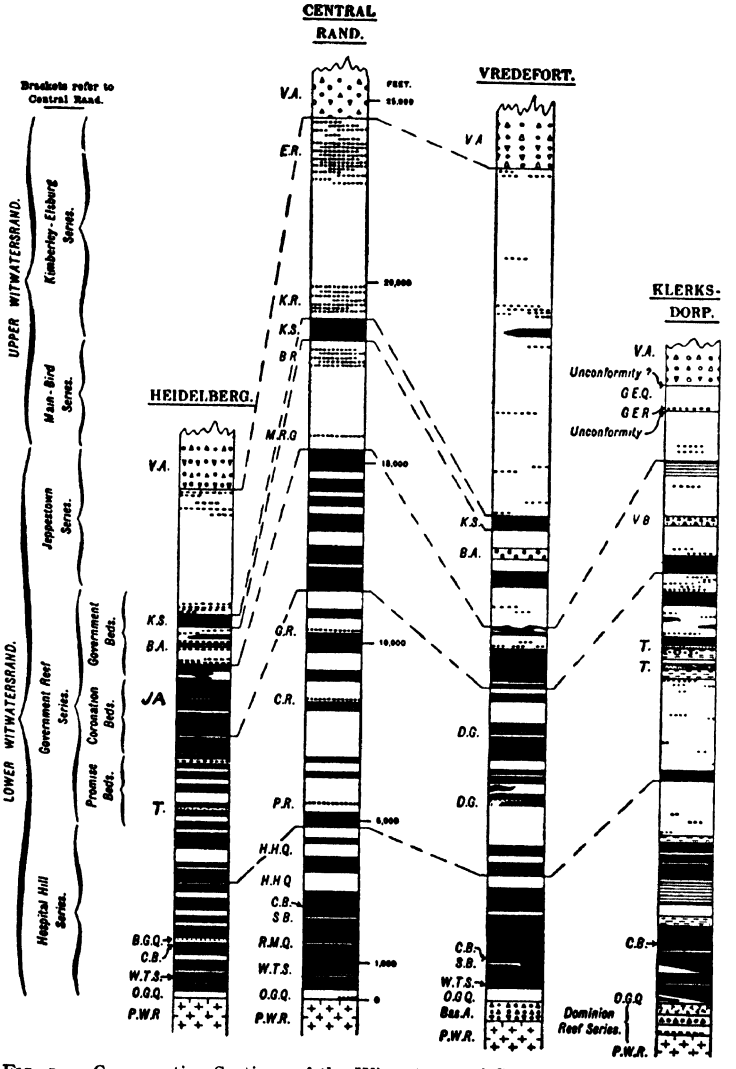


FIG. 14.—Comparative Sections of the Witwatersrand System :—*P.W.R.*, Basement rocks; *O.G.Q.*, Orange Grove Quartzites; *W.T.S.*, Water Tower Slates; *C.B.*, Contorted Bed; *H.H.Q.*, Hospital Hill Quartzites; *P.R.*, Promise Reef; *C.R.*, Coronation Reef; *T.*, Tillite; *G.R.*, Government Reef; *J.A.*, Jeppestown Amygdaloid; *M.R.G.*, Main Reef Group; *B.A.*, Bird Amygdaloid; *B.R.*, Bird Reefs; *K.S.*, Kimberley Shales; *K.R.*, Kimberley Reefs; *E.R.*, Elsburg Reefs; *G.E.R.*, Gold Estate Reef; *G.E.Q.*, Gold Estate Quartzite; *V.A.*, Ventersdorp Amygdaloid.

have been changed to quartz-sericite schists. Absent at Ventersdorp, this assemblage is exposed along the sides of the Platberg Syncline and of the basins beyond, past the old Dominion Mine, lying apparently conformably below the Orange Grove Quartzite, but thickening to the south-west as the latter thins. The acid lavas appear in a belt passing Ottosdal and include a thick band quarried for that unique ornamental substance, " Wonderstone " (p. 499).

(*c*) The recording by Molengraaff, confirmed by van Eeden,[1] of arkose and chert, reposing on the primitive rocks to the west of Schweizer Reneke and overlain by quartz porphyries, forms the link with those similar occurrences in the adjacent Cape previously termed the " ZOETLIEF SERIES " which, while including some sediments, consist mainly of acid volcanics. That series [2] took its name from a farm north of Vryburg, where the rocks make a belt 28 miles long with arkoses and flagstones overlain by quartz porphyries, etc., and those in turn by tuffs, breccias, quartzites and shales, thin limestones and cherts, with an occasional interbedded lava flow. Some of these cherts are altered rhyolitic tuffs. Scattered exposures are known in the stretch between Mafeking and Prieska, the formation usually resting unconformably on the Old Granite and showing *disturbance and erosion* prior to having been overlapped discordantly by Ventersdorp beds.

Such is the case a little north of Mafeking, at the saltpan at Stella, at Skatkist east of Vryburg and at Motiton. At Taungs [3] the porphyries are underlain by a thick body of conglomerate, arkose, and greywacké, with a median zone of micaceous shales and grey tuffs.

The mine shafts at Kimberley [4] have proved up to 1000 feet of light greenish quartz porphyries and acid amygdaloids. Between them and the Old Granite in the Kimberley Mine come 300 feet of nearly horizontal sediments, including conglomerates with pebbles of granite, gneiss, quartzite, and quartz, but the floor must undulate, since in the De Beers Mine the porphyries rest directly on the granite.

These acid lavas reach the surface in occasional inliers to the west and south-west of Modder River Station and project through the Dywka tillite at Beervlei, Hopetown, where they include markedly amygdaloidal and felsitic types. A good succession from the granitic

[1] O. R. van Eeden, *T.G.S.S.A.*, 1947, xlix, 277.
[2] *Ann. Rep. G.C. for* 1905, 235 ; *for* 1906, 14 and 93 ; *for* 1907, 50 and 164.
[3] F. C. Truter and C. A. Strauss, *T.G.S.S.A.*, 1942, xliv, 161.
[4] R. H. Rastall, *Rep. S.A.A.A.S. for* 1905 *and* 1906, 275.

base upwards appears in the T'Kuip Hills near Omdraais Vlei, arkoses, conglomerates and breccias being followed by acid lavas and overlapped by a locally developed group of basic lavas and sediments with quartz porphyry pebbles—known as the Kuip Series—and those in turn discordantly by the Ventersdorp lavas. The acid porphyries in the much sheared belt near Uitspansberg, Prieska, may belong to this series.

In the thin sections of many of these porphyries the quartz crystals are corroded and the feldspars altered. The amygdaloidal varieties show silicification, though flow structures and perlitic cracks may be preserved. In many of the lavas no ferromagnesian constituent can be seen, but in others enstatite, or pseudomorphs after that mineral, is present.

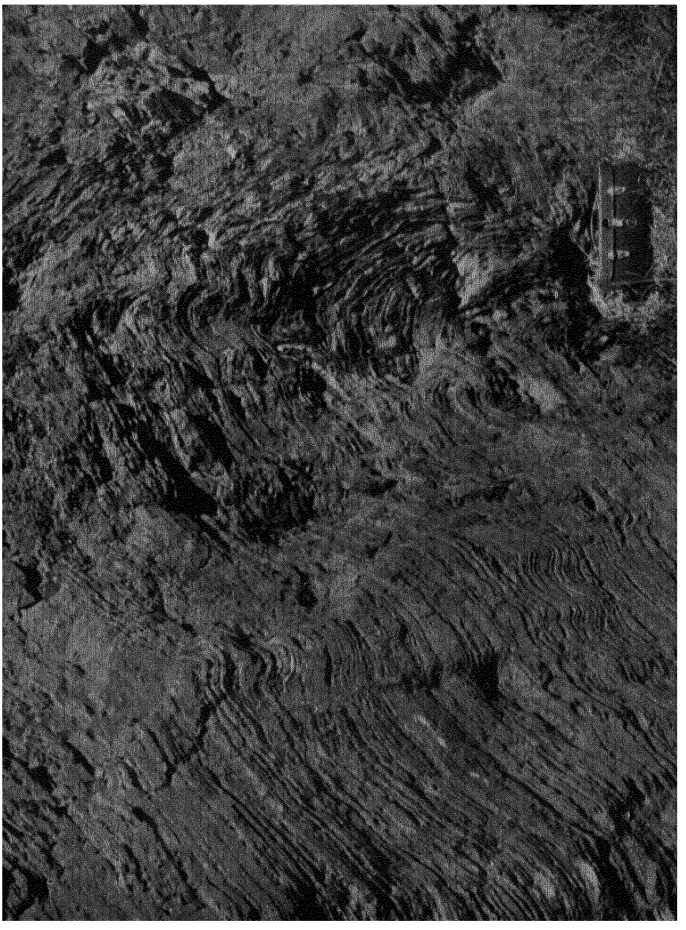
(2) **The Hospital Hill Series** (3000-6000 feet).—(a) *The Orange Grove Quartzites* take their title from the suburb of that name, where they make an escarpment rising several hundreds of feet above the Old Granite and the basic schists to the north. West of Randfontein, between Ventersdorp and Klerksdorp, and north of Parys, they also produce a marked feature in the landscape. The (basal) contact with the older formations, which is rarely seen, is a *normal unconformity*, there being occasionally a thin basal conglomerate with pebbles of vein-quartz and sometimes of chert, as, for example, just east of Orange Grove or some miles due east of the town of Heidelberg,[1] but inclusions are normally wanting.

The quartzites are hard, whitish or yellowish, medium or fine grained, and include one or more bands of slate.

(b) (i) *The Water Tower Slates* and (ii) *the Contorted Beds.*—These two groups, here placed together, consist of flaggy reddish, brownish, or purplish-black slaty beds, sometimes banded or striped; with them are associated some thin quartzites. The beds are decidedly ferruginous, in places markedly so, particularly towards the base of the group, the iron being in the form of magnetite and hæmatite.

An extreme phase constitutes the conspicuous and well-known "Contorted Beds," consisting of finely banded siliceous and jaspery rocks, very rich in iron ores and practically identical with the "Banded Ironstones" so characteristic of the more ancient formations of South Africa. The wonderfully regular

[1] A view of these quartzites resting on the granite at the latter locality is given in Hatch and Corstorphine, *The Geology of South Africa*, First Edition, 1905, Fig. 24.



Contorted band, Hospital Hill Slates, Jan Smuts Avenue, Johannesburg.

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alternation of red, white, and black stripes has also given it the name of " Calico Rock," and the laminæ are often most remarkably crumpled and minutely faulted (Plate III), although the slaty and less ferruginous beds above and below are only slightly affected. The thin section shows an aggregate of cherty silica in which lie crystals of magnetite, specular iron and some pyrite, and there can be no doubt that these rocks are entirely of sedimentary origin. Being hard, this zone almost invariably gives rise to a feature ; it is also most persistent and thus constitutes a most valuable marker, being recognisable not only throughout the Rand and Heidelberg areas but also south of Greylingstad (Oudhoutdraai 126), in the Vredefort area both north and south of the Vaal, and in strong outcrops throughout the Ventersdorp and Klerksdorp districts.

On the Rand there are two thin quartzite " markers " in this slaty group, the lower known appropriately as the " Ripple-Marked Quartzite," the upper and coarser as the " Speckled Bed " from the rusty weathering of grains of clastic feldspars therein ; it has been recognised near Parys and to the north of Klerksdorp. Some slightly calcareous bands are reported by Rogers below the Contorted Beds.

(c) *The Hospital Hill or Green Quartzites* consist of several thick banks of very hard quartzites alternating with slates, the former possessing a characteristic pale greenish tinge and showing on freshly broken surfaces—more particularly in the upper bands —the peculiarity styled " sago-structure." Grains of clear and unusually well-rounded quartz, dark by reflected light, are set very evenly in a white, extremely fine-grained matrix composed of minute angular quartz fragments. The rock in consequence is very different to any ordinary quartzite and indeed in its appearance strongly recalls boiled sago. These sago-like bands, being almost confined to this group, enable these beds to be identified in distant localities, and are hence of importance. The green tint is due to sericitic mica carrying a little chromium, derived from grains of detrital chromite (Frankel). The basal quartzite in Heidelberg contains lenses of a peculiar black grit with grains of black chert, and to the south-east of Greylingstad a thick quartzite carries similar fragments. Black ferruginous or magnetic shales are intercalated in the upper part of the group in Ventersdorp and Klerksdorp.

(3) **The Government Reef Series** (4000-6000 feet) consists of a group in which quartzites alternating with argillaceous beds predominate, including some grits and a few pebbly layers, certain individual bands of which—mainly to the west of Johannesburg—have been exploited under the names of the *Promise, Government,* and *Coronation Reefs* in ascending order, and in Klerksdorp as the *Buffelsdoorn* and *Afrikander Reefs.* East of the town of Heidelberg there are occasional lenses of an uncommon blue grit, and one of these, just below the equivalent of the "West Rand Shales," carries boulders of various rocks—some of which are glacially striated, so that the rock has the character of a *tillite.* This horizon has been located on the Rand at Roodepoort and Witpoortje and is seemingly present to the south-west of Randfontein. Observed by Rogers a little to the west of the Buffelsdoorn Mine near Klerksdorp, further work has shown the presence there of two tillites, each less than 100 feet thick usually, on horizons at least 600 feet apart. The boulders in these various glacials range up to over a foot in length and include quartzites, lavas, and jaspers of various kinds. Glacial or fluvioglacial action has been detected on other horizons and may be wider spread than currently thought. Blue grits attain a thickness of many hundreds of feet on Hex River and Driefontein to the south of Greylingstad, with occasional boulders of quartzite and other rocks, while north of Parys a dark grit apparently on a higher horizon includes granite pebbles. A thin conglomerate in the Promise Reefs near Roodepoort is remarkable through enclosing pitted and wind-etched pebbles (dreikanter).

The shales of the series are reddish and purplish, and are often quite ferruginous, several bands being striped and rich in magnetite. The most important of these is known under the name of the *Coronation* or *West Rand Shale* from its good development in the west, and has been identified near Parys but not with certainty in Klerksdorp, though more than one magnetic horizon has been detected there.

(4) **The Jeppestown Series** (1400-3700 feet) includes much argillaceous material and for that reason tends to occupy depressions and to be soil-covered. Being furthermore less resistant than the overlying Upper Division, it has experienced marked shearing and thrusting in many places and has indeed been almost entirely cut out by major strike-faulting in the Central Rand.

Consisting largely of reddish-weathering shales in Heidelberg, but with a fair proportion of quartzites in Vredefort and on the Rand, it shows a progressive thickening towards the West Rand with a coarsening of the materials when traced into Klerksdorp, where quartzites compose fully three-fourths of the succession with some scattered pebbles and occasional, though patchy, conglomerates, such as the Veldschoen Reefs there and at Ventersdorp. At the same time, because of scattered minute octahedra of magnetite, the dark green shales near the base develop magnetic properties and produce a strong "anomaly." The quartzites are often yellowish, reddish, or darkish, weathering readily, and so differ from those of the other series. A marker of great value in deep boring is the thin *Jeppestown Amygdaloid* at about the middle of the series. Absent from the Central Rand and Vredefort, it is represented in Heidelberg by volcanics and tuffs and has been pierced by certain boreholes in the East Rand, on Luipaards Vlei and West Witwatersrand Areas and identified in Klerksdorp on Palmietfontein and Elandsheuvel and in the Odendaalsrus area.

The topmost soft shales, red-weathering at outcrop, pass up into the hard reddish quartzites of the "Red Bar," placed by Mellor at the base of the Main Bird Series.

B. The Upper Division

Comprising a thick mass of quartzites, grits, and conglomerates, it is dominantly *arenaceous*, there being only one important argillaceous zone—that of the Kimberley Shales. The thickness is uniformly about 9000 feet throughout the Central Rand, thinning eastward of Boksburg and south-eastward through Heidelberg to about half that value, the subdivisions varying correspondingly. Because of such diminution the East Rand Basin has proved to be shallower than would be deduced from outcrops alone. On the contrary, around Vredefort, a figure of 15,000 feet has been measured by Nel, the upper portion attaining its maximum development in the Parys sector, with coarsening of the materials.

Owing to its more massive character it has resisted subsequent earth movements much better than the Lower Division, in which bodies of weaker shales alternate with zones of relatively brittle quartzites; consequently it is not traversed by thrust-planes in

anything like the same degree as the lower beds, though extensively broken by minor faults and intersected by dykes. Nevertheless, sericitic mica has been developed under pressure and shearing in certain strata and chloritoid generally, while the originally soft sands and pebble-beds have been converted into intensely hard quartzites and conglomerates by the deposition of secondary silica. To the presence of pyrite and gold in certain pebbly bands called *Reefs* or *Bankets* is due the immense economic importance of this part of the system.

Subdivisions.—The early prospectors labelled the principal conglomeratic and (generally) auriferous bands, which alternated with barren quartzites and grits, " Main Reef Series," " Bird Reef Series," etc. ; but it would be better to employ the term " series " in the orthodox sense and to speak of the various groups of conglomerates simply as the " Reefs."

In consequence the Division is split into the two groups—the Main-Bird Series below and the Kimberley-Elsburg Series above, including in the latter the strata from the base of the Kimberley Shales up to the bottom of the Ventersdorp lavas or sediments. The base of the Upper Division used to be drawn at the bottom of the Main Reef itself, but it has been found more satisfactory from the practical standpoint to follow Mellor [1] in taking the divisional line at the junction of the shaly beds of the Jeppestown Series with the group of overlying quartzites up to six hundred feet thick that include the Main Reef horizon.

(5) **The Main-Bird Series.**—A vast amount of detailed information about the reefs, their peculiarities, variation, position, values, etc., has slowly been accumulated by the various mining companies and has been well summarised by Carleton Jones,[2] yet even today there are differences of opinion regarding the correlations of bankets, particularly for the area west of the Witpoortje fault.

(*a*) The Main Reef Zone, which is far and away the most important economically, normally embraces on the Rand—in upward succession—the three individual and payable conglomerate bands known as the *Main Reef*, *Main Reef Leader*, and the *South Reef* (Fig. 15), located within a maximum width of 250 feet of strata at Randfontein Estates (where other payable bankets are present) and Robinson Deep, but tapering out eastwards.

[1] *T.G.S.S.A.*, 1915, xviii, 13. [2] *P.G.S.S.A.*, 1937, xxxix, p. xxiii.

(i) *The Carbon Leader*, 14-30 inches thick, is of recent discovery [1] within the western section of West Witwatersrand Areas situated some 200 feet beneath the Main Reef and a few feet below that useful marker the " Green Bar," a fine-grained rock with abundant chloritoid. The fact that the content not only of carbon, but of gold, is often high, makes this a most valuable reef on the Far West Rand.

(ii) *The Main Reef* is the most strongly developed in the West as well as in the Central Rand, being in certain mines a dozen or more feet thick, in others only a few inches. Thus, from its maximum of 25 feet at Venterspost it thins south-westwards to a few feet. East of Germiston it becomes intermittent and is not individually recognisable in the East Rand. The pebbles are throughout of uniform average size, including many of white

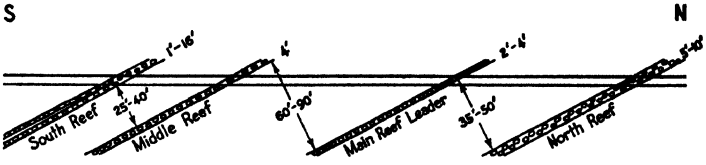


FIG. 15.—Section through the Reefs, eastern side of the Ferreira Deep Mine, Central Rand.

vein-quartz, while there may be no very clear hanging-wall or foot-wall; in addition, the conglomerate may contain partings and lenticles of quartzite. Its gold content, however, is not so subject to variation as in the other bankets.

(iii) *The Main Reef Leader*—or commonly " *The Leader* "—while usually thinner, though ranging up to 10 feet, is wonderfully persistent, being not only prominent right through the Central Rand and westwards to Roodepoort at least, but traceable over the whole East Rand and even identifiable at the Nigel—an extreme distance of 40 miles. In places it is in contact with the Main Reef, but beyond the E.R.P.M. over the East Rand it rests directly upon the Jeppestown shales with sharp basal unconformity in places (Joseph). It is " graded," that is to say the biggest pebbles are usually located at the bottom of the band, the smallest at the top, while the footwall is always sharply defined, being in many mines a fine-grained quartzite or a hard

[1] R. A. Pelletier, *T.G.S.S.A.*, 1938, xl, 152.

slate (see v) (Fig. 16). On the other hand, the gold value fluctuates a lot.

(iv) *The South Reef*, or *South Reef Leader* as it is sometimes called, is from 2 to 5 feet thick and banded, that is to say it tends to display sheets of small pebbles alternating with layers of quartzite, and is peculiar in that whenever it becomes attenuated (so that the pebbles of the bottom layer vanish) the plane of the reef may still show pyrite and carbon and contain gold in sufficient amount to render the thin stratum workable. It is not individually traceable east of Boksburg. Throughout the Central Rand the thin "*Middle Reef*" is present between (iii) and (iv).

It is noteworthy that the above succession applies only to the Rand-Heidelberg area, and that around Parys there are no grits or pebbly bands at the base of the Main-Bird Series.

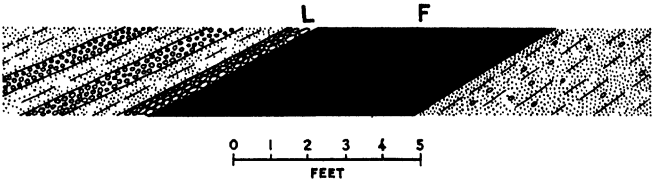


FIG. 16.—Section through the Main Reef Leader, Ferreira Deep Mine, showing the "Leader," L, resting on the "Footwall," F, of black unstratified mudstone.

(v) *Variabilities in the Strata between the Reefs.*—The stoping-out of colossal amounts of reef has provided a good picture of the complex behaviour of the various pebble-beds and their enclosing strata when followed along the strike and dip over the greater part of the fields.

Considering the nature of the beds, including as they do layers of coarse material, such as could only have been transported by pretty strong currents, it is indeed surprising that more irregularity is not found and that the individual conglomerate horizons actually persist over such wide areas.

While in the Central Rand the Main Reef Leader may lie directly upon the Main Reef, on proceeding eastward the two bankets come to be separated by an increasing thickness of beds which may be either quartzitic or argillaceous. The slaty rock of the latter phase is from its dark colour known as the "Black Bar," and has a lenticular habit, swelling out to 100 feet or more, only to thin again beyond, and occupying channels scoured out

in the footwall. Under the microscope it is found to be built up of quartz and chlorite with numerous small crystals of chloritoid.

Sometimes the beds just below the Main Reef Leader pass into the type termed "*Bastard Reef*," in which pebbles of considerable size are scattered through a matrix which varies from an argillaceous to a gritty material; there may also be irregular stratification in the mass. It varies enormously in thickness, from nothing up to 40 feet, and is mineable in parts.

Previously it had been supposed that, when followed eastwards, the Main Reef thinned out, whereas the Leader retained its individuality; but Carleton Jones [1] has marshalled evidence to show that all the pebble-beds, from the Main right up to the South Reef—which occupy a depth of 50 feet at the Nourse Mines—come together when followed eastwards, so that in the East Rand Proprietary Mines they constitute a single body averaging 9 feet thick—the "*Composite Reef*"—that is actually the "Main Reef Leader" of the East and Far East Rand and the "Nigel Reef" of the Heidelberg district.

Below the Main Reef there is on the Central and West Rand up to 500 feet of quartzites, grits, and pebble "leaders," including the unimportant *North Reef*, which become finer in grain downwards, to merge with the "*Red Bar*" resting on the shales of the Jeppestown Series. Useful indicators for this group are the "Boulder Marker" and the higher "Square Pebble Zone" of Randfontein and Venterspost, the former recognisable at places on the Central Rand.[2] In the Blue Sky section of the East Rand Proprietary Mines these basal quartzitic beds thin out abruptly, causing the Leader to rest directly upon the Jeppestown Shales. In the north of the East Rand sporadic bodies of conglomerate, associated with quartzites and known as the "*Footwall Reefs*," occupy north-south trending erosion-channels in the footwall in places thousands of feet wide and many feet deep, and are overlain by the Main Reef Leader, in places with *strong unconformity* (Fig. 17). They and the associated quartzites are in places mineralised and may carry workable values, as in the Brakpan Mine. Their extension down the dip will form an important research.[3]

(vi) *The Banded Pyritic Quartzites*, discovered in 1906, are now known from many of the mines of the Central and nearer

[1] *P.G.S.S.A.*, 1937, xxxix, p. xxiii.
[2] E. R. Roberts and D. Kransdorff, *T.G.S.S.A.*, 1939, xli, 225.
[3] See E. H. A. Joseph, *T.G.S.S.A.*, Annexure 1931, xxxiv, 37.

East Rand, occurring as elongated lenses in, or most commonly below, the Main Reef Leader, and tending to occupy channels produced by the removal of the Main Reef. They suggest rearrangements—with some concentration—of the original pebble-bed and recall seasonally banded sediments. One important stretch trending west-south-west traverses the Meyer and Charlton Mine. Identical deposits are now known from other horizons and localities, *e.g.* at the Great Western Mine near Reitzburg. They vary from mere streaks to bodies up to 80 feet in thickness and consist of very dense dark quartzites in which occur, alternating with barren rock, layers rich in pyrite that

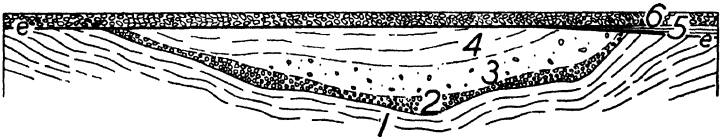


FIG. 17.—Diagrammatic relation of the Main Reef Leader to the Footwall Reefs in the Far East Rand (*adapted from* E. H. A. Joseph). 1, Jeppestown Shale; 2, Footwall Reef; 3, Bastard Reef; 4, Quartzitic Shales; 5, Main Reef Leader Shale; 6, Main Reef Leader; e-e, Line of Erosion.

thin and thicken but maintain their continuity for quite a distance relatively speaking (Fig. 18). These pyritic bands are not infrequently auriferous, being sometimes of surprising richness —ounces to the ton—and the zone is in consequence being mined on a fair scale on several properties, for example the Geldenhuis Deep and Simmer and Jack. High values tend to accompany the thicker pyrite seams. On one view these were originally stratified "black sands" rich in detrital iron ores (and occasionally in alluvial gold); on the other, they were lenses of sand having certain porous laminæ which the sulphide-bearing solutions (bringing in the gold) followed.

(b) *The Upper Leaders.*[1]—Under this name have been placed quite a number of reefs clustered within the first 200 feet of strata overlying the Main Reef Leader in the area between Benoni and Brakpan. Carrying small and large pebbles as well as carbon seams, they are rather irregularly developed and become of less importance towards the east, but have yielded much gold on the Randfontein Estates, Van Rhyn, and New

[1] G. Carleton Jones, *P.G.S.S.A.*, 1937, xxxix, p. xlvii.

Modder mines and are likely to be mined more extensively and widely in the future.

(c) *The Bird Reefs.*—Included in the great thickness of quartzites following the Main Reefs are numerous small-pebbled conglomerates distributed at intervals through several hundreds of feet of strata. These are the *Livingstone Reefs* and, higher up, the *Bird Reefs*, traceable right through the Rand, though poorly

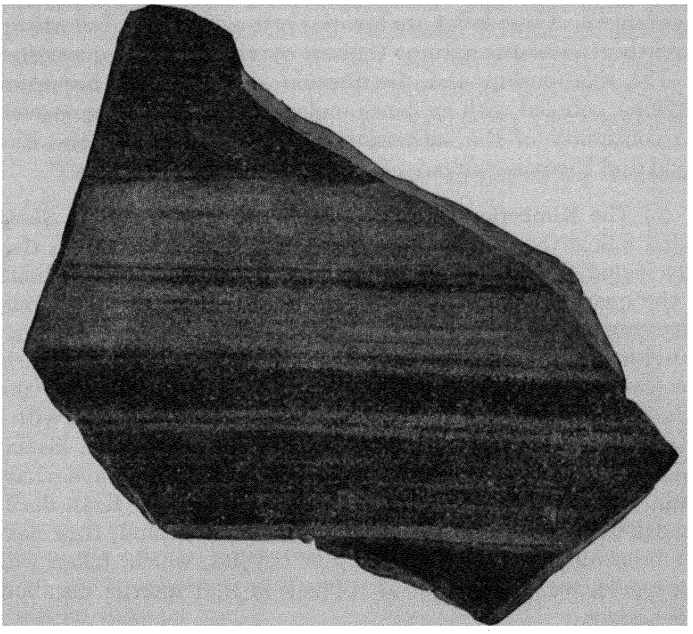


FIG. 18.—Banded "Pyritic Quartzite," Cinderella Deep. The bright bands indicate the "brassy" pyrite. (About three-fifths natural size.) *After* Voit.

developed in Heidelberg. Auriferous in places, they have been worked on a few properties, as on the New Modder and the Consolidated Main Reef respectively.[1]

(d) *The Bird Amygdaloid and Marker.*—Following some thin quartzites comes the Bird Reef Marker, a thin band of hard, fine-grained, greenish rock carrying chloritoid and chlorite, perhaps partly built up from volcanic ash, a stratum traceable

[1] Uranium is an important constituent of at least one of the Bird reefs, and production of this has now been commenced (Editor).

from the Crown Mines to the East Rand Proprietary Mines. At the Boksburg Lake it is overlain directly (Haughton and Nel) by a thin amygdaloid to be correlated with the well-known Bird Amygdaloid that runs from the East Rand Proprietary Mines eastwards throughout the East and Far East Rand and Heidelberg into the Parys area with thickness ranging usually between 200 and 350 feet. Although absent from the Central Rand this lava reappears in the west on the western part of Luipaards Vlei (Lagrange). These lavas are invariably much altered, but are apparently of a basaltic nature: they are overlain by more quartzites.

The relationship and distribution of these two important horizons, coupled with evidence underground, prove conclusively the continuity of the succession from the Central to the East Rand and the *non-existence of the so-called "Boksburg Gap."*

(6) **The Kimberley-Elsburg Series.**—(a) *The Kimberley Shales* which follow the foregoing are not entirely argillaceous, as they may include thin bands of quartzite and are usually transitional to the quartzites above and below; forming, however, the only slaty zone in the dominantly quartzitic Upper Division, they constitute quite an important horizon. Although from 300 to 500 feet thick they are almost everywhere on the Rand concealed by a belt of soil. In mine workings they are grey or black with a satiny lustre, and in thin section under the microscope display much rutile in the form of minute needles. Dolomitic layers have been reported from Randfontein (Roberts and Kransdorff). Persistent from the Far East to the Far West Rand, they have not been identified in Klerksdorp or beyond, which, taken with other evidence, would hint at a break in that quarter on about this horizon.

(b) *The Kimberley Reefs* range through the several hundred feet of succeeding strata in bands and stringers, being best developed in the West Rand, where the layers of conglomerate are thicker and the pebbles greater and packed more closely together. Pyrite is abundant, partly as "buckshot" pyrite, while carbon may be present. Good values have been found, though the tendency is for payable bodies to be lenticular. Mining is being carried out to the south of Krugersdorp, *e.g.* Luipaards Vlei Estate and West Rand Consolidated, and on the East Rand at Daggafontein and Springs; but in the past these reefs were worked at a number of other places, for instance at

the " Heidelberg-Roodepoort " near Greylingstad and, as the Amazon Group, in Vredefort.

(c) *The Elsburg Reefs.*—Succeeding (b) comes a great thickness of quartzites and grits, frequently false-bedded, and then somewhat below the top of the system a mass of pebbly beds with inclusions sometimes over 6 inches in diameter. The group takes its name from the village of Elsburg south of Germiston. While pyrite is a common constituent, gold is present in small quantity only. In Heidelberg, though some large inclusions can be found in the conglomerate layers, the pebbles are less frequent and smaller and the seams which they make less persistent. In Klerksdorp the Gold Estate Reef quartzites and conglomerates can belong only to this series.

The relationship of these beds to the succeeding Ventersdorp System is discussed in Chapter VI.

The Free State or Odendaalsrus Gold Fields [1]

Introduction.—The astounding and prodigious campaign of drilling following the epoch-making discoveries around Odendaalsrus is difficult to interpret since so much of the mass of new information thus acquired is not yet available or correlated. While shaft-sinking is in active progress, diamond-drill cores from points dotted over an area at least 120 miles from north to south and 50 miles across form the prime source of information, supplemented by widespread geophysical surveys. All this has sprung from the original boring sunk by Western Holdings on Aandenk No. 227 through Ventersdorp rocks into Witwatersrand quartzites during 1933-34.

A. SURFACE GEOLOGY.—The country is flattish with gradual rise to the east. Outcrops of the older rocks are limited to a few inliers peeping out through the obscuring mantle of sandy soil concealing Karroo beds (with occasional sills of dolerite) that dip south-eastwards at between one-half and one and a half degrees.

[1] Apart from brief articles in the mining journals and a host of minor press notices the outstanding contributions are those by R. Borchers and G. V. White, *T.G.S.S.A.*, 1943, xlvi, 127, and A. Frost, R. C. McIntyre, E. B. Papenfus, and O. Weiss, *ibid.*, 1946, xlix, 1, together with the discussions thereon. For Borehole positions, depths, and returns, the plans issued by The Technical Map Service, Johannesburg, may be consulted.

The writer is under deep obligations to many colleagues for helpful information and discussion, but takes full responsibility for the views expressed below.

Situated to the north of the Karroo geosyncline, the pre-Karroo floor is locally very uneven, differences of over a thousand feet in a few miles having been found.

Between Odendaalsrus and Ancona Siding there are frequent outcrops of Ventersdorp rocks that disclose a gentle arch with roughly north-south axis running through Aandenk (227) with regular dip towards the west, where they are brought up by faulting on Mooiplaats (169), still dipping west. Volcanics, presumably of Ongeluk age, project at Rustig Siding to the north-east. The Old Granite is exposed on Roodevalnek (697) to the north-north-west of Dealesville to the south-west. In peculiar position, overlain apparently by Lower Beaufort shales, on Welgeluk (492) five miles south-east of Verkeerdevlei township south-east of Brandfort is a small patch of coarse granitic rock that was thought to be the Old Granite. Since boring at Sunnydale (784) proved over 3000 feet of Karroo beds, it is more probable that that material is due to reaction between dolerite and Karroo sediments or is an inclusion of granite in the dolerite adjacent. Apart from these few exposures over an enormous area, the nature of the deeper rocks has been determined entirely by borings, hundreds of which have been drilled, some to over 8000 feet in depth.

B. SUB-KARROO GEOLOGY.—The covering—mainly Ecca beds—is relatively thin in the west, averaging 600-1000 feet about Odendaalsrus, but increasing south-eastwards to 1500-1900 feet near Henneman and Ventersburg, to 2000 feet just south of Theunissen, to 2500 feet at Brandfort and to over 3000 feet a little south of Verkeerdevlei and at Sydenham, just south of Bloemfontein.

Beneath it, but well to the north-east, must run the deep syncline of Transvaal rocks, traceable from Potchefstroom past Viljoenskroon village and Rustig Siding to Kroonstad, with the Dolomite intersected at and not far to the north-west of that town, thereby creating conditions hardly favourable towards prospecting along that belt. On the west again the Old Granite has been reported at 136 feet on Geduld (1272), at 337 feet on Weltevreden (190), and at 771 feet on Tygerfontein (189), south of Wesselsbron.

Ventersdorp rocks, largely volcanics, and in places thousands of feet thick without having been bottomed, are almost ubiquitous

so far south at least as Brandfort and east as the Bloemfontein-Kroonstad railway. Over the limited area that will constitute this field the scores of boreholes drilled have proved this formation sufficiently thin to bring the underlying Witwatersrand beds to within the limits of practical mining. Because of the *steeper thermal gradient* hereabouts, such has currently been set at about 5000 feet, at which depth a rock-temperature of about 108° F. is anticipated.[1] In the southern part of Western Holdings the Ventersdorp covering was largely removed by pre-Karroo erosion.

The various stages of the Witwatersrand System parallel stratigraphically and tectonically those of the Klerksdorp district.

C. STRUCTURE.—Bearing in mind the limitations of borehole evidence, and the wide gaps in many places, only a generalised outline can be submitted; each new boring must bring about some reorientation of ideas.

As delimited, the mining field consists of a fairly well-defined *trough* or "*graben*" of Upper Witwatersrand strata which trends N. 15° W., and which may form the southerly continuation of the "Platberg Syncline" of Klerksdorp. It extends past Odendaalsrus, where it is almost 8 miles wide, to beyond the Sand River, and, narrowing to under 6 miles, for an unknown distance in the direction of Theunissen. Lowered between broad blocks of Lower Witwatersrand beds—by strong faulting on the east, and by warping coupled with some faulting on the west—this strip is for the most part still roofed by Ventersdorp lavas. Subsidiary warping has given rise to a series of secondary domes and basins within the main trough (Fig. 19). On the west dips may be steep, strong flexuring being indicated by St. Helena No. 1 B.H., and *échelon* structures can be suspected there. Near the margins there are also signs of multiple and complex faulting. Within the trough low dips are apparently scarce, inclinations—based on cores—being mostly between 20 and 40 degrees, which suggests the existence of tilt-blocks rather than repeated foldings. Considerable fracturing is evinced from the profiles drawn through chains of boreholes, and by the cores themselves, while the fact that not a few borings have gone directly into "footwall" hints at a "venetian blind-structure" as the result of east-west tension, with the absence of reef-bearing ground along narrow belts.

Fracturing—and probably tilting as well—of at least two

[1] *T.G.S.S.A.*, xlvi, 133.

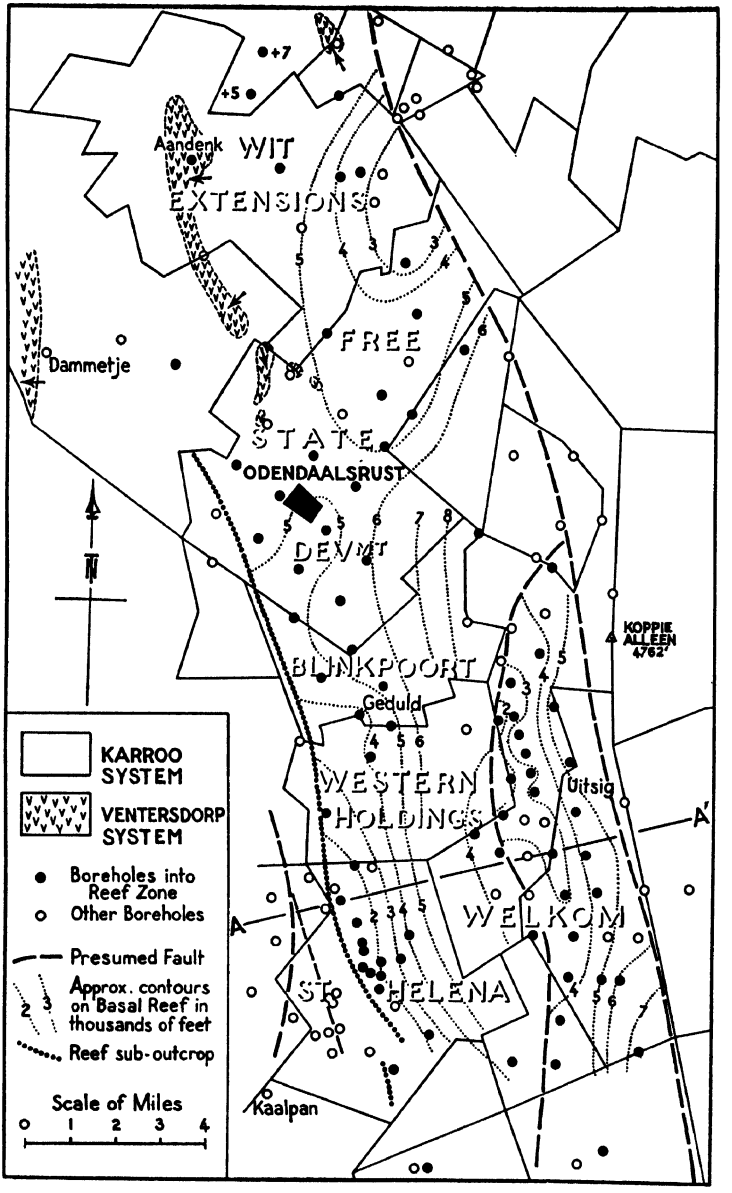


FIG. 19.—Provisional Structural Map of the Odendaalsrus Gold Field, Orange Free State.

periods, pre- and post-Ventersdorp, is indicated, the latter exemplified by the Dammetje-Aandenk section in the north-west, where there has apparently been a strong downthrow to the east marginally. The data are as yet too limited and conflicting to enable more than the principal faults to be plotted tentatively.

Conspicuous are the two main areas of shallow " reef zone," namely Western Holdings and the Welkom Lease, with a long deep zone, faulted on the east, in between. Depths of 1000-2000 feet are present on Western Holdings, but over much of this field 4500-5000 feet is usual, while the reefs dip in places to great depths, for example just east of Odendaalsrus, and again in the extreme north. Few boreholes have been drilled in the 24-mile stretch northwards and westwards to the Vaal River, but the base of the volcanics sinks to below 6500 feet on Klein Brittanje (76), rising to under 3000 feet on Fairview (39) and Angra Pequina (8), thus indicating an intermediate shallowing.

Outside the field, as currently defined, a patch of " reef zone," possibly in part faulted, rests on the eastern block; though not delimited as yet it may prove to have a considerable extension.

Stratigraphical.[1]—The succession would in brief seem to be :—

6. Ventersdorp System — Volcanics and sediments

(*Disconformity* or *unconformity*)

Upper Division

5. Elsburg Series — Conglomerates and quartzites with the Big-pebble Conglomerate at the base

(*Unconformity*)

4. Main-Bird Series — Quartzites / " Reef Zone " / Footwall Quartzites

Lower Division

3. Jeppestown Series
2. Government Reef Series
1. Hospital Hill Series.

[1] Ideas are still being shaped and it is not easy in this over-simplified account to harmonise such views as have been expressed, certain of which could only be settled by actual mining.

A. WESTERN FLANK.—(*a*) *The Hospital Hill Series* seems represented by the highly magnetic shales struck on Dammetje (247) in the north-west, and perhaps by (*b*) the quartzites and less magnetic dark blue to black shales cut on Kaalpan (65) and the strongly magnetic shales and white glassy quartzites on Wolvepan (85) that are dipping at angles of 30°-85° and strike at about N. 10° W. (from geophysical survey). (*c*) Although the thick " Prairie Quartzites " to the east of (*b*) have been ascribed by Frost to the Upper Division, those medium to coarse quartzites, white to grey, with their darker shaly laminæ and thin shaly intercalations strongly recall, and may well represent, the arenaceous facies of the *Government Reef Series* of Klerksdorp (Borchers), especially the lower part thereof, and could well be following (*b*) conformably. Folding being present in St. Helena No. 1, a normal succession on the western side of the trough could be presumed with minor folding, perhaps *en échelon*, a surmise not out of harmony with the torsion balance surveys through a strike distance of 9 miles, though cross-faulting is also present. The bankets struck in St. Helena No. 1 could under this view belong to the Coronation or Promise beds. Furthermore, the eastern edge of the trough, on Uitsig (694) and Mimosa (1676), is formed by alternations of quartzites and shales like those immediately beneath the Jeppestown beds. It can be suggested that on the western side of the field the Jeppestown Series has been largely cut out by faulting.

B. EASTERN FLANK.—(*d*) Quartzites and shales (some greenish-black) that included a contemporaneous lava-flow with, in places, blue grits below it, have been penetrated on the north on Taljaards Dam (86), Waterpan (263), and Smithsdal (523), and on the east on Nooitgedacht (74), Tafelbaai (1013), De Bron (645), and Homestead (668), dipping eastwards at moderate angles, though perhaps step-faulted, showing that Jeppestown beds must form a large proportion of the terrain to the east under a covering of Ventersdorp rocks, mostly lavas. (*e*) Running southwards from Dankbarheid (2181) to Erfdeel (188) is a belt in which presumably higher strata have been cut that contain auriferous conglomerates correlated usually with those of the Reef Zone.

C. CENTRAL OR MINING BELT.—(*f*) Boring has generally ceased upon striking the so-called " *Footwall Quartzites*," but these have been sectioned to a depth of perhaps 3000 feet at

Uitsig (694) No. 1 in the east and St. Helena No. 3 in the west, and clearly form an important group, the relation of which to the older assemblages has not yet been clearly established.

Upwards these quartzites pass into, and alternate with, peculiar greenish speckled grits hundreds of feet thick marked by tiny fragments of cherty rocks, shale, quartzite, and quartz, and remarkably like those of a correspondingly thick assemblage in Klerksdorp that falls between the Ada May and the Vaal Reefs (p. 71). These Footwall Quartzites are overlain—possibly with disconformity (Frost)—by the Odendaalsrus Reef Zone.

(*g*) *The "Reef Zone."* [1]—The two dominant reefs are 40-80 feet apart.

(i) The *Basal Reef* ranges from 6 inches to 6 feet thick and averages 2 feet. Just how far its non-recording in some boreholes is due to non-deposition or to friability is uncertain. While pebbly in the south-east, it is normally a badly-sorted grit with scattered tiny pebbles mostly of quartz. Showing blebs and splashes of pyrite, it is spotted with carbon and often carries a carbon seam and visible gold. Values are often concentrated over about 6 inches, with remarkably high core-assays over much of the southern half of the field (150-300 inch-dwts.) that have culminated in some amazing returns from Boreholes 1 and 2 on Geduld. Generally, values fall off towards the east and north-east of Odendaalsrus town, but the wide variations obtained from core-deflections make estimates uncertain. This will be the principal working reef.

Above, with a thin silicified quartzite at the base, come 30-60 feet of drab yellow very fine-grained quartzites that are more argillaceous eastwards, where a part thereof forms that important marker, the "Khaki Shales."

(ii) The *Leader Reef*, sharply defined, is from 6 inches to 5 feet thick and averages 2 feet, with well-packed pebbles of white quartz and grey quartzite ½-1 inch in diameter, good mineralisation and some carbon. Values are variable though generally low, but best apparently to the south-east of Toronto (415).

It is followed by several hundred feet of strata—quartzites passing up into shale and conglomeratic beds that include the "A" and "B" reefs, with good values occasionally in the central region.

[1] This non-committal term is used instead of "St. Helena Reef Zone" (Frost), which includes higher strata as well.

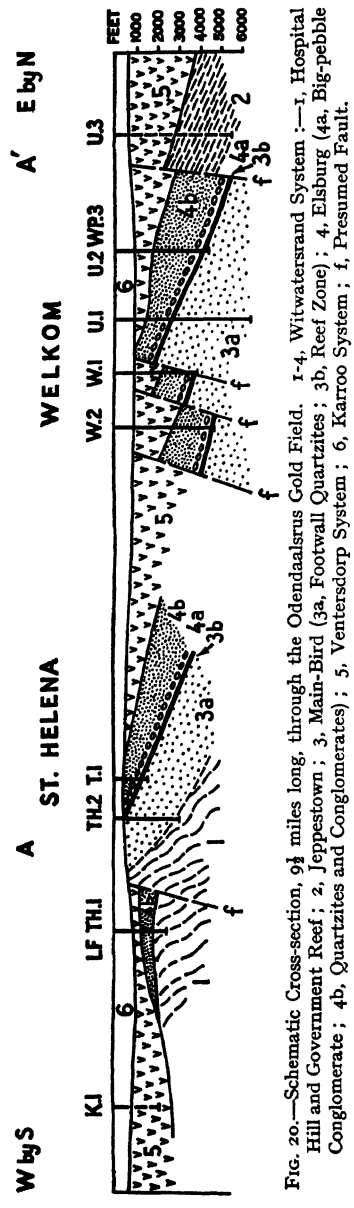


FIG. 20.—Schematic Cross-section, 9¼ miles long, through the Odendaalsrus Gold Field. 1-4, Witwatersrand System :—1, Hospital Hill and Government Reef; 2, Jeppestown; 3, Main-Bird (3a, Footwall Quartzites; 3b, Reef Zone); 4, Elsburg (4a, Big-pebble Conglomerate; 4b, Quartzites and Conglomerates); 5, Ventersdorp System; 6, Karroo System; f, Presumed Fault.

(*h*) The *Big-Pebble Reef Marker* is a persistent horizon ranging from a few to 178 feet thick, signalised at its base by white, rounded, or muffin-shaped quartz pebbles 3-6 inches across, but carrying only traces of gold. An angular unconformity at its base has, it is learned, been measured in certain boreholes.

(*i*) This passes up into a variable group with maximum thickness of almost 2000 feet, though generally less, in which quartzitic alternate with, or grade into, conglomeratic beds that terminate in a thick body of poorly-sorted conglomerate [1] carrying angular, elongated or rounded cobbles mainly of grey or dark quartzite, chert, felsite or dark slate set in a dark to nearly black quartzitic matrix. Inclusions of basic lavas are scanty. The group attains its greatest development within the trough, thinning towards the west (Fig. 20). Although very like some of the sedimentary stages within the Ventersdorp succession this remarkable accumulation becomes finer grained and quartzitic when traced northwards and eastwards, and more like the typical Elsburg beds. At its summit no true "contact reef" has yet been reported.

[1] Also termed the "agglomerate-conglomerate" or the "Ventersdorp Basal Conglomerate."

(*j*) *The Ventersdorp System.*—Several groups of sediments and volcanics overlie the so-called "Lower Lavas," which, when traced over this wide region, appear to transgress across successive stages of the Witwatersrand System,[1] including the highest horizons (*h*) and (*i*), with the suggestion that within the trough and along its margins the Ventersdorp rocks have shared in some at least of the downwarping and faulting. North-westwards from Odendaalsrus, to across the Vaal River, borings have shown great thicknesses, including unusual amounts of acid lavas and porphyries and associated rocks, fancied to represent high stages of the system.

(*k*) *Age of the Reef Zone.*—Turning to Klerksdorp, the quartzite and conglomerate zones (*h*) and (*i*) will compare with the strata extending downwards to the disconformable base of the Gold Estate Reef, and can hence be assigned to the Elsburg Series. The still lower zones of peculiar speckled grits form a link between the two areas and suggest the equivalence of the Vaal Reefs and the Odendaalsrus Reef Zone, and indicate a position well up in the Main-Bird Series.[2] The absence from both areas of that persistent marker, the Kimberley Shales, is not without significance.

[Since these lines were written by du Toit, a considerable number of boreholes which cut the reefs have been radiometrically logged by the Geological staff of the Atomic Energy Board. Study of these logs has led D. J. Simpson to postulate a definite stratigraphical correlation between the Basal Reef of the Orange Free State field, the Vaal Reef of the Klerksdorp area, and the Monarch Reef of the Bird reefs of the western part of the Witwatersrand. For further details of the basis of this correlation, the reader should consult papers by Simpson in *T.G.S.S.A.*, 1951, liv, 99, and *T.G.S.S.A.*, 1952, lv, 33 and 133.]

(1) *Conditions of Deposition.*—The impression gathered by the writer is of a lengthy "rift-valley" of the asymmetrical or "trap-door" type, like those of East Africa, developed about middle Witwatersrand times from a shallow syncline that received sands, pebbles, and coarse shingle—mainly from the west—with differential sagging, and was overwhelmed by lavas, etc., with further movements. The Reefs would mark out temporary marine transgressions—presumably

[1] R. Borchers and G. V. White, *T.G.S.S.A.*, 1943, xlvi, pl. xxxi.

[2] The Reef Zone has been placed in the Ventersdorp System by Frost (*et al.*) and in the Elsburg Series by Borchers and White.

from the east, when waste from the rising area of Lower Witwatersrand beds to the west became sorted and concentrated. It is interesting to note that, while good values continue to be found south of the Zand River along the extension of the belt, those outside and to the east thereof are generally low. Conditions would seem to have been curiously like those that prevailed over the Far West Rand during Main Reef time.

The Gold-Bearing Reefs or "Bankets"[1]

The dominating "Main Reef" industry obscures the vital fact that *auriferous conglomerates occur on many horizons throughout the System*, certain of which are being or were formerly mined, especially outside the Rand. Much of what follows about the Main Reef will apply equally to those other bands and *vice versa*.

(1) In contrast to all auriferous deposits known at the time save those of Tarkwa, Gold Coast, the gold-bearing material discovered in 1886 proved to be a stratified quartz-pebble conglomerate with the precious substance confined to the matrix thereof. All the same the term "*reef*" was bestowed on this uncommon type of ore-bearer; but the alternative designation of "banket" given by the local folk to the brownish oxidised conglomerate from its resemblance to almond-rock is certainly more distinctive and has since become thoroughly established.

Indeed this term has been extended to auriferous conglomeratic rocks elsewhere, though differing in important respects from the Rand reefs: for instance, certain conglomerates and pseudo-conglomerates in Southern Rhodesia. It would be well, therefore, if the name "Banket" or "Banket reef" were to be restricted, as R. B. Young has suggested, to conglomeratic bands of rather similar type, namely to those possessing pebbles mainly of vein-quartz set in a compact quartzitic matrix; he regards, further, neither pyrite nor gold as essential constituents on account of their generally small proportions.

[1] The literature of these deposits is very extensive, but the subject will be found fully set forth and discussed by R. B. Young, *The Banket*, 1917, and C. B. Horwood, *The Gold Deposits of the Rand*, 1917; see also J. W. Gregory, *Trans. Inst. Min. Met.*, 1908, 2-41; F. W. Voit, *Min. Journal*, Sept. 1908; E. T. Mellor, *T.G.S.S.A.*, 1915, xviii, 11-56; P. A. Wagner, *P.G.S.S.A.*, 1918, xx, pp. xix-xxiv; L. Reinecke, *T.G.S.S.A.*, 1928, xxx, 89-119; 1930, xxxiii, 111-33; L. C. Graton, *Ec. Geol.* (Suppl.), 1930, xxv, 1-185; the symposium by various authors in *T.G.S.S.A.* (Annexure), 1931, xxxiv, 1-92; G. C. Jones, *P.G.S.S.A.*, 1937, xxxix, pp. xxiii-lviii; R. A. Pelletier, *T.G.S.S.A.*, 1938, xl, 127-62; M. S. Fisher, *Bull. Inst. Min. Met.*, 414, March 1939; W. P. de Kock, *T.G.S.S.A.*, 1941, xliii, 85.

(2) *Conditions of Deposition.*—There can be no doubt, from the way in which the individual zones of the system thicken when traced to the north-west and west, that the sources of the sedimentary material lay in that quarter, corroboration being found in an increasing coarseness in certain horizons in those directions. The ancient schists and the old granites and gneisses have clearly furnished the materials for these sediments.

P. Macadam has been able to match a high proportion of banket pebbles with rock-types common in the Barberton beds, while identical formations are known in Pietersburg, Southern Rhodesia, and Mafeking, and could formerly have been present in the Rustenburg and Ventersdorp areas. Auriferous quartz veins and impregnations are known in those very regions. The stratigraphy and lithology of the system accord well with the hypothesis of progressive denudation of sources largely composed of schists and gneisses, the unroofing of intrusive granites, the releasing of quartz from the contact zones and the coarsening of the detritus, with less gold, as the batholithic granites were eaten into. Gold was brought forward continuously, but only concentrated under favourable conditions.

The evidence suggests that the immense thickness of sediments was deposited in a north-east south-west trough presumably, and that the progressive elevation of the sources to the north and west led to the shallowing of the basin, the overlapping of the younger groups, such as the Elsburg and Ventersdorp, across the older horizons in those directions, for instance on the northern side of the Rand and in the Klerksdorp area. The marked lithological change from the Lower to the Upper Division can indeed be ascribed to such intra-formational movements.

While the strata containing the various reefs have unquestionably been spread out over a wide even surface situated at or close to sea-level, opinion has been strongly divided as to whether that surface consisted essentially of a sea- or lake-floor, marine beach, delta-flat, or piedmont-plain. Such differences of opinion are partly due to the fact that observation has perforce been restricted to the margins of the Rand goldfields, since the deeper parts of that basin are still inaccessible. Graton has favoured a sea-floor of substantial though not excessive depth ; Becker, Gregory, and Young a wide marine beach ; Mellor has given many strong reasons for a deltaic origin, while Reinecke has reasoned convincingly for terrestrial conditions resembling those covering the deposition of the Siwaliks in the Indo-Gangetic region, or, it may be added, the Irrawaddy Series of Burma. The region must then

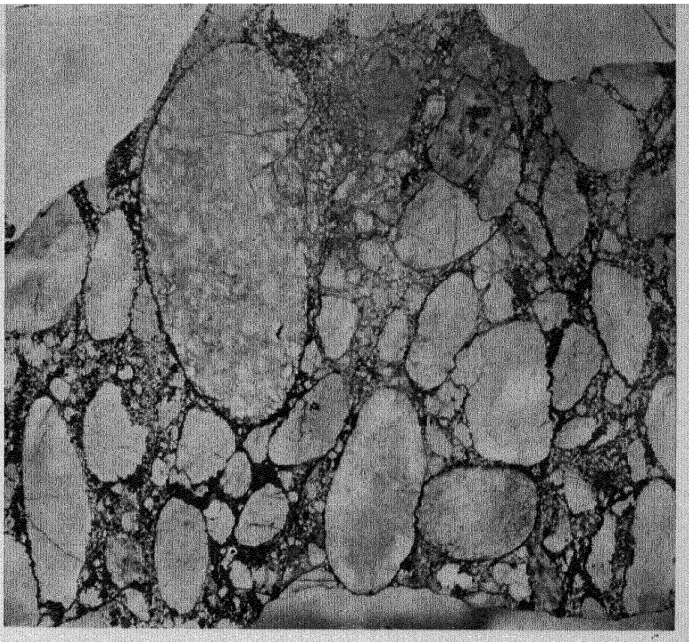
have formed a barren waste, even under any reasonable rainfall, since vegetation, such as we know it, had not yet come into being; erosion and deposition must therefore have been rapid.

The coarseness, thickness, and persistence of the pebble-beds imply an abundance of gravel-supply—possibly from accumulations partly of glacial origin in the mountains, for the evidence of the tillites should not be forgotten. Mellor has argued that such a persistent conglomerate as the Main Reef Leader could well have been the product of a series of discharges of exceptional volume that worked over masses of varied materials, sorting them and spreading out the pebbles in a continuous sheet, sometimes over sand, sometimes over mud, a view not far removed from that of Reinecke. Contemporaneous water-courses are indeed indicated by the various " wash-outs " in or beneath the banket, while " braiding " of the channels is assumed to be disclosed by the " pay-streaks," to be discussed later, that mark out the courses of transporting currents. Certain phenomena, however, suggest the transgression of a shore line, for instance the regularity, concentration, and extent of most of these pebble-sheets, their surprising repetition, the plane of unconformity below the " Leader " on the northern margin of the East Rand, the irregular shingling of the conglomerates and the prevailing " muffin-shape " of the larger pebbles, for they are somewhat flattish on one side (Plate IV, 1). In some respects, therefore, the deposits can be compared with modern marine " placers," though on a far wider scale, a hypothesis which the writer finds he has no option but to support.

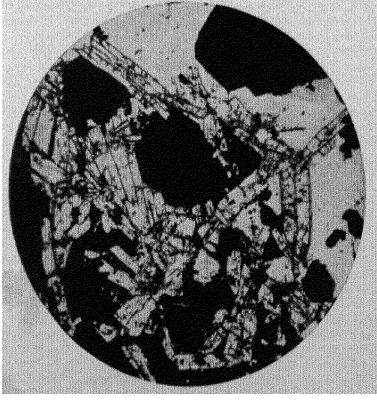
Whichever view be adopted, it is generally admitted that the pebble-beds and the enclosing sands must have remained for some time after their deposition—how long is uncertain—unconsolidated and therefore permeable. Furthermore, it may be inferred that such heavy minerals as invariably characterise coarse sediments of every epoch would have been deposited by preference along with the pebbles—iron ores chiefly, also grains of gold or of the platinum group of metals; indeed it can be surmised that there would have been a concentration of such detrital minerals within the grits and conglomerate layers and particularly at or near the base of the latter, should the footwall be sharp.

The strata were subsequently cut by a host of dykes of varying types and ages, and by numerous quartz-veins [1] along the bedding

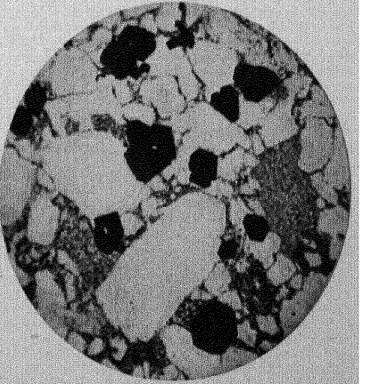
[1] R. B. Young, *The Banket*, 1917, 92-7.



1.—Large-sized section showing the shapes of the pebbles. ×$\frac{1}{2}$.



2.—Pyrite replacing quartz and moulded on chloritoid. × 56.



3.—Matrix of banket containing well-formed crystals of pyrite partly replacing quartz grains. ×12.

[*Face page* 100

and across it ("verticals")—particularly near dykes—that may carry talc, tourmaline, sulphides, etc.

The Pebbles of the Banket.—Averaging some 70 per cent. by volume, the bulk consists of vein quartz—glassy white, mottled grey, and black, or strikingly opalescent blue—but there are also represented quartzites, black and green banded cherts and red jaspers, quartz porphyry and more rarely tourmalinised rocks and greenish slaty and schistose types, almost invariably fresh. These different varieties are irregularly distributed within the numerous reefs of the Rand [1] and outside districts.

The pebbles may attain a length of several inches and in certain areas of 6 or even over 8 inches, though just under an inch is the usual size; the larger ones are generally oval and either sub-angular or well-worn, but with the tendency to a "muffin shape," while the smallest ones are sub-angular to angular (Plate IV, 1). The cherty inclusions are flattish with rather sharp edges and may be partly or completely replaced by pyrite.

In their varying sizes they are sometimes crowded together, sometimes scattered through the quartzitic matrix; the upper or lower limits of the band may be sharp or it may grade into quartzite; occasionally the banket may be reduced to a single line of pebbles or even a mere parting, while a band may split into several seams which may or may not reunite.

The Minerals of the Banket.—The conglomerates are less siliceous than currently supposed, the silica content ranging from 73 to 86 per cent., due to the presence of secondary silicates, chiefly of iron. (1) Manifestly of *primary, detrital, or allogenic character* are first the pebbles and next the bulk of the lesser grains of quartz, derived obviously from a distance; but, despite the very considerable mineral alteration or metasomatism of the banket, uncertainty attends the allocation of only a few of the other minerals, present in exceedingly small proportions always.

The *diamond* has been recovered in surprising numbers from the six mines on the north of the East Rand, mainly from the Modderfontein "B" Mine, and from the Gold Estate Reef, Klerksdorp, in both cases usually of a greenish colour. *Iridosmine* (*Osmiridium*) is present throughout the Rand, but chiefly on the north of the East Rand, always in minute amounts that range

[1] H. Pirow, *T.G.S.S.A.*, 1921, xxiii, 64-97.

up to 1 oz. per 1000 tons of ore, but well worth collecting. In 1951, 6,883 oz. were exported, valued at £243,478. Horwood maintained its secondary origin, but, as Young has set forth, many of the grains are very well worn, and the allogenic character is accepted by Graton. *Chromite* is far commoner than currently supposed and is even visible in some of the quartzites. It and the iridosmine can safely be referred to a source in the ultrabasic igneous rocks. Significantly, the Black Reef in the Klerksdorp district has yielded greenish diamonds and chromite. *Zircon* is abundant in small crystals and dull grains. *Ilmenite*, partly altered to leucoxene, has been found scantily, while its former presence is betrayed by the invariable secondary rutile. *Corundum* and *garnet* are surprisingly rare.

(2) The constituents of assuredly *secondary* or *authigenic character* are *quartz* (in part), *chlorite, chloritoid, sericitic mica, calcite, dolomite, rutile, tourmaline*, and *carbon*, with the sulphides *pyrite* and occasionally *pyrrhotite, marcasite, blende, galena*, as well as *monazite, cobalt arsenide*, and *uranium* compounds, some of which could nevertheless have been of sedimentary origin.

Metasomatism has played a very important part in the conversion of the original porous sands and pebble beds into *quartzites* and *bankets*. *Authigenic quartz* has been deposited between the detrital quartz grains with partial solution of the latter, and occasionally on pebble surfaces, while sutural or "stylolitic" solution along bedding-planes has been recorded.[1] In addition many of the new-formed minerals, such as pyrite and chloritoid, have in their turn suffered partial replacement by secondary quartz.

Chloritoid is common in tiny ragged crystals and is specially abundant in certain layers, such as the Black Bar, Green Bar of the Far West Rand and Bird Reef Marker, but is widely spread through the system, occurring even in the Orange Grove and Bird Amygdaloids. *Chlorite* in green scales is characteristically developed in the vicinity of basic igneous contacts, so that the beds become darker there. *Sericite* is ubiquitous. These three minerals could well have been developed from the finer-grained fractions of the sediments. *Rutile* occurs as fine aggregates and as minute needles. *Carbon*, first noticed in the Buffelsdoorn Gold Mine near Klerksdorp, has been found to have quite a wide

[1] R. B. Young, *T.G.S.S.A.*, 1945, xlvii, 137.

distribution and is present as granules from 2 mm. in diameter downwards, laminæ or veinlets, the latter cutting across the bedding in places. Some reefs, particularly rich in this substance, are called " Carbon Leaders," *e.g.* on the Far West Rand and Odendaalsrus. Its occurrence not only in the matrix but in the pebbles themselves suggests a secondary and possibly liquid or gaseous origin. Algal life may, however, have been responsible.

(3) *The Pyrite Replacements.*—Pyrite, which, though variable, constitutes roughly 3 per cent. by weight of the banket, but about 12 per cent. of the matrix, and is more abundant in the latter than in the associated quartzites, occurs in several forms—as well defined crystals, as irregular patches, as rounded grains, or as spherical or discoidal aggregates. The authigenic character of the first-named form is obvious, as the mineral replaces the quartz of the matrix (Plate IV, 3) and encroaches on the pebbles as well, while in the second form the pyrite is often moulded on or encloses chloritoid (Plate IV, 2). Two generations of pyrite may be present, but its formation has clearly been spread over a considerable period (Fisher). The rounded grains and aggregates range from microscopic particles to lumps nearly an inch in length, one type, common at the Rietfontein Mine north of Germiston, being termed " buckshot pyrite " from its prevalent shape.

Generally the surface is smooth, suggesting a water-worn inclusion, but occasionally minute crystal faces can be observed ; within the mass a radially fibrous structure is common. For long these forms were thought to be rolled particles of detrital origin ; indeed, they are still known as "*pyrite pebbles.*" To Horwood and Young is due our knowledge that these so-called " pebbles " are actually replacements, generally of the matrix, but sometimes of foreign inclusions ; in a number of instances banded cherty pebbles exhibit such replacement by pyrite either along their exteriors or along particular laminæ, the ferruginous layers being especially affected.

Although usually assumed to have been wanting in the case of the Banket, convincing evidence of *detrital pyrite in existing placers* is on record.[1] The metasomatic nature of the bulk of the pyrite in the banket must, however, be admitted, while the same is the case with the banded pyritic quartzites, the pyritic streaks

[1] Discussion on paper by M. S. Fisher, *Bull. Inst. Min. Met.*, 1939.

of which are identical in composition and microscopic structure with the pyritised matrix of the " reef." The other sulphides are present in very limited amounts and not unusually make their appearance near the contacts with basic intrusions—a significant feature.

(4) *The Gold.*—Excluding the oxidised ore, this element is but rarely visible, being found as hackly grains, as minute flakes, and occasionally as thin layers or as films coating nodular pyrite, or as veinlets passing out from the matrix into cracks in the quartz pebbles and even partly replacing them (Kransdorff). In the richer reefs, for example in the " Leader " at Randfontein Estates and in the Ventersdorp Contact Reef at Venterspost, it may be coarse and is then frequently accompanied by *carbon*, on which it may be moulded or which it may penetrate, the latter having presumably exercised a reducing action on the auriferous solutions. On the contrary, carbon may be present without gold. In the sulphides the gold may occur as sub-rounded to idiomorphic particles, especially in the pyrrhotite.[1] Despite the doubts often expressed, it would appear that gold has actually been found as " nuggets." The general distribution of gold within the reefs is variable, with values tending to be highest at or near the footwall, but occurring at the top of The Leader (Macadam).[2] The quartz veins cutting the richer parts of the bankets occasionally carry gold, some astonishingly rich pockets being struck from time to time, but there is no proof that such veins continue downwards for any distance. They may carry some talc, tourmaline, epidote, or sulphide.[3]

For practical purposes the gold may be taken to be confined to the pyritic parts of the matrix, being enclosed by and intergrown with the sulphides in a fine state of division, but it can be recovered by treating the sufficiently finely-ground rock by amalgamation or cyaniding. The gold is always accompanied by *silver*, in the general ratio of about 9 : 1, though the proportion may vary greatly between one stope and another, and may in places exceed 1 : 5.[4] The richer the banket, the less the percentage of silver. The richness of the alloy is much higher than in alluvial and placer fields generally, which fact has been advanced by

[1] R. S. Pelletier, *Jnl. Chem. Met. Min. Soc.*, 1940, xl, 353.
[2] See *T.G.S.S.A., Annexure*, 1931, xxiv, 84.
[3] R. B. Young, *The Banket*, 1917, 92.
[4] See Horwood, *loc. cit.*, and J. G. Lawn, *P.G.S.S.A.*, 1925, xxvii, p. xix.

Horwood as an argument against such a possible origin for the precious metals. The objection is not unanswerable, for it is equally striking that the ancient gold reefs of Rhodesia, which can under the " placer theory " be considered as the probable source of part of the metals, are frequently quite high in silver.

Origin of the Gold.—No longer is this an academic question, for it is essential today to have a guiding hypothesis in order to direct effectively development work on the thinner reefs, lenses, or pebble-streaks through which the life of a property may be prolonged. Much has indeed been achieved during recent years and much remains to be investigated.

There has been a vast amount of discussion upon this problem, but curiously many of the arguments put forward on behalf of one of the two main rival theories can indeed, with but slight modification, be employed in favour of the other. While an enormous amount of patient research has been made in recent years, it must candidly be admitted that the criteria available are not so obvious nor individually so convincing as to compel universal acceptation of any one view, though collectively they definitely favour the so-called " Placer Theory."

Already in 1903 De Launay had summarised the various speculations and grouped them under three heads, according to whether the gold was assumed to have originated (*a*) before, (*b*) during, or (*c*) after the conglomerate had been deposited. These are usually known as (*a*) the *Placer*, (*b*) the *Precipitation*, and (*c*) the *Infiltration* or *Hydrothermal Theory* respectively. Each of these concepts is, of course, dependent on individual interpretation.

The second of these supposes that the pyrite and gold were precipitated chemically from the water in which the sediment was being laid down, which, among other difficulties, involves the rather improbable coincidence of conglomerate deposition with the concentration of gold in the waters.

(*a*) THE PLACER THEORY, favoured by the majority of the Rand geologists, regards the gold as having been mechanically deposited with the pebbles as the result of the denudation of pre-existing auriferous rocks. The bankets would, therefore, represent very ancient placers within which such detrital gold had been subsequently dissolved by circulating waters and then redeposited—almost *in situ* it may be said. Their metasomatism

would then be integral with the metamorphism of the system generally, as the result of deep burial, folding, and thrusting. Under this view the sulphuretted hydrogen required for the formation of the pyrite could, as stressed by Gregory, have been produced from organic matter originally contained in the sediments, and only as much sulphur would have been retained as could have been fixed by the free iron oxides present. In that reaction the ferric sulphate, first formed, would have dissolved any gold, while the ferrous sulphate or sulphide, produced later, would have precipitated it; hence the intimate association of the gold with the pyrite. As a by-product would have been graphite. High gold values are incidentally associated with dark-edged pebbles (Reinecke). Numerous assays have shown the enclosing quartzites to be very low in gold and heavy minerals, and the shales barren (Macadam). Secondary quartz, sericite, chlorite, and chloritoid are universal within the system, and for their development would have needed little or no additions from outside.

(i) *Minerals.*—Of the heavy minerals such as magnetite, ilmenite, hæmatite, and chromite, which ought also to be represented, the first three are conspicuously scanty in the banket, having under this view been converted into pyrite (or pyrrhotite) by the action of sulphuretted solutions.

Viewed in this light the banded pyritic quartzites are interpreted as originally stratified auriferous black sands rich in iron ores, such as are well known in many parts of the world. Microscopic examination shows that this material displays characters identical with those of the banket matrix, while the gold is confined to the sulphide layers, so that when the latter are thick the values are generally high, though abundant pyrite does not necessarily mean the presence of gold. A feature characteristic of hydrothermal deposits, namely mineral zoning, is strikingly absent from the bankets (Cameron).

(ii) *Erosion Channels.*—Carleton Jones has reported from the Benoni area refilled erosion channels *below* the Main Reef that trend roughly north-south with walls that may be sharp. He has furthermore regarded the Banded Pyritic Quartzites of the Central Rand as occupying wide erosion-hollows *excavated in* the Main Reef, while similar "wash-outs" have been recorded by Gregory, Mellor, and Voit in the reef, the features of which would

indicate that the gold was introduced into the pebble-bed *before* the erosion by the currents of such channels, and that it must therefore have been deposited contemporaneously with the pebbles. The erratic distribution found is in accord with the mode of deposition of such heterogeneous materials. Of special significance are certain isolated patches of rich banket completely surrounded by barren quartzite noted by Gregory and Mellor, proving that the gold contained therein must be allogenic.

Weighty is the evidence that the Ventersdorp Contact Reef (Beetz ; de Kock) and the Black Reef (Frankel), while in no way different petrographically, have in places acquired part of their gold from the eroded edges of Rand bankets, and must thus be in large degree of " placer " origin. It is indeed becoming more clear that even small basal unconformities are attended by local enrichments and may have economic importance.

(iii) *Pay-Streaks.*—While the gold is often unevenly distributed within the banket, and may be concentrated towards the base or summit, it is definitely associated with a larger size of pebble, indicative of stronger current-action or wave-action, and in turn of carried heavy minerals, and the " shoots " of richer reef or " pay-streaks " are stated to coincide in the main with the belts of coarser conglomerate and to agree apparently with the direction of transport of that material as deduced from the orientation of the pebbles—where such can be determined—the reduction in pebble-size and the pitch of the current-bedding. The reef is normally continuous between one pay-streak and the next—perhaps reduced in thickness or in pebble-size or with quartzite partings, while the roof may close down on the shale footwall—of course having lower gold values.

The recognition on assay-plans of such distribution-patterns has proved of immense service in the developing and working of unknown ground. For the Central and East Rand these pay-streaks are arranged in a fan-shaped manner, radiating towards the east and south-east (Fig. 21),[1] representing, according to Reinecke,[2] the courses of the transporting currents. Diverging across a vast flood-plain, and unrelated to structure, faulting or depth from the surface, they were essentially " Alluvials." New data have been added by Bridges.[3]

[1] Based on observations by Reinecke, Bridges, and company mining plans.
[2] L. Reinecke, *T.G.S.S.A.*, 1928, xxx, 89.
[3] R. J. Bridges, *P.G.S.S.A.*, 1943, xlv, p. xxxii.

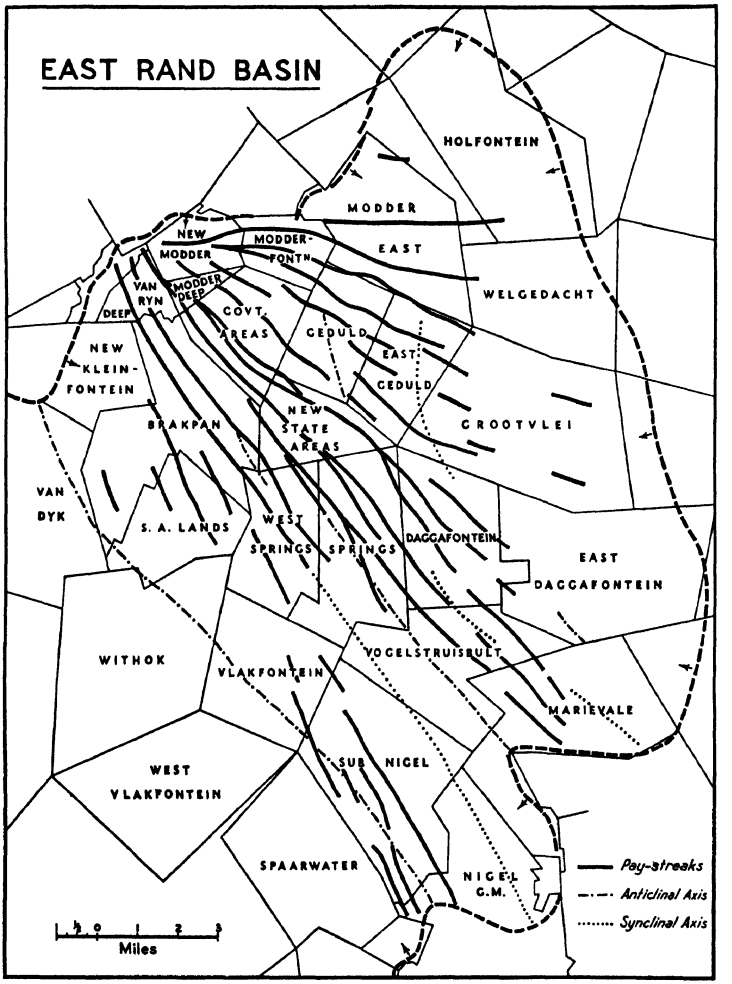


FIG. 21.—Showing the principal warpings, and the positions and directions of the Pay-streaks, in the Main Reef Leader of the East Rand Basin (*adapted from* L. Reinecke and R. Bridges). Arrows indicate direction of dip at the outcrop or sub-outcrop.

On the contrary, the regularity of the "Main Reef" and its unconformable base over the East Rand could only have been the result of marine planation. The shoots might therefore have

been shallow marine rearrangements, a view that finds support from experiments on pebble-transport and the detection of " oscillation-ripples " at Randfontein.[1] Indeed, the general pattern strongly suggests pebble-bars graded by shore-currents and pulsated by waves advancing north-eastwards over a subsiding coastal plain of loose deltaic materials and blown sands. The reefs would then be " Drowned Pebble-beaches," extended progressively landward under regional subsidence. Their rough coincidence with tectonic structure in the East Rand (Fig. 21) could conceivably have been due to faint crustal warpings that acted as broad riffles. Indeed, it is felt that right through Witwatersrand times *" Reef-formation " must have been intimately connected with crustal adjustments.*

(iv) *Permeability.*—The supposed superior permeability of the conglomerates to mineralising solutions can seriously be questioned, since the spaces between the pebbles and larger grains must in the beginning have been well packed with smaller quartz particles—as is so clearly depicted in Plate IV, Fig. 1—as well as with more finely divided material—since recrystallised—thus giving the pebble-bed an initial texture not far different from that of the contiguous sands—since changed into quartzites. Peculiarly, the porous Bird Reef Amygdaloid lying next to the auriferous Bird Reefs remains unmineralised, though it may carry chloritoid. Noteworthy are those cases where the reef has become reduced to a line of scattered pebbles or even a faint parting, and may yet carry high values. Such a plane can hardly be pictured as a major channel-way. Furthermore, Young has shown that the metasomatic changes in the rock must in great part have taken place *subsequent* to the cementation of the conglomerate and inferentially, therefore, *after* the latter had lost its original permeability. Study of the contacts with dykes shows that the rocks were cemented *before* such intrusion. Had the gold been introduced during or after such intrusion, occasional conglomerate pockets could be expected to have escaped mineralisation, which is not the case. It is therefore important to note that water-worn boulders of banket, sometimes auriferous, are represented in the Ventersdorp conglomerates at Kromdraai and Ventersdorp, which show distinctly that the metasomatism had been completed by the close of the Witwatersrand period. Angular lumps from the

[1] E. R. Roberts and D. Kransdorff, *T.G.S.S.A.*, 1939, xli, 225.

breccias of Wolverand west of Klerksdorp carry pyrite, granular carbon, and gold (Beetz). This would dispose of the idea that post-Witwatersrand dykes or deep-seated intrusions were essentially responsible for the introduction or redistribution of the gold.

(*c*) THE INFILTRATION OR HYDROTHERMAL THEORY, advocated by Horwood and Graton [1] particularly, stresses the scarcity of heavy detrital minerals, the fineness of the gold and the absence of nuggets. It views the metamorphism of the strata as dominantly hydrothermal and due essentially to ascending heated solutions introducing pyrite, some of the quartz and secondary substances together with the gold into the pebble-beds. The latter, being coarse and in the still unconsolidated or only partly cemented state, would have afforded an easier passage for such solutions than the enclosing quartzites and so have constituted the major channel-ways. Alternatively, there was present in the conglomerates some precipitating agent such as carbonaceous matter or pre-existing pyrite. It is, however, hard to understand why the supposedly impermeable banded pyritic quartzites should have become so well impregnated although pebble-beds adjacent might be poorly mineralised ; furthermore, certain bands in these quartzites, although rich in pyrite, carry no gold.

Auxiliary passage-ways are postulated in the abundant quartz veins and stringers associated with or cross-cutting the reefs, certain of them, particularly in rich areas, carrying gold as well as sulphides. Their hydrothermal nature has never been disputed, but the fact that their gold values are normally greatest next to, though less than within, the reef, suggests that they have derived their *minerals from the latter.* Admittedly some wonderfully rich pockets are occasionally struck with metallic gold ramifying through the quartz.

A highly important part in the metasomatism of the banket is deemed to have been played by the intrusive rocks, mainly basic dykes together with a few sills—possibly by concealed deep-seated bodies as well—the fractures then produced enabling the mineralising solutions to enter the permeable pebble-beds at numerous levels in addition to travelling along them. A parallel could indeed be cited in the Pilgrims Rest goldfields. The same solutions which brought in the pyrite, or alternatively produced it from detrital iron ores, could on this assumption equally well

[1] *Ec. Geol.* (Suppl.), 1930, xxv, 1-185.

have introduced the gold and also compounds of carbon, which last is of widespread distribution. Only occasionally do the intrusions themselves carry gold, as in the case of the South Rand Dyke.

It must, nevertheless, be admitted that the instances in which particular local enrichment in the reefs can definitely be correlated with proximity to intrusions are remarkably few, although the reefs are intersected by a host of such dykes. In such positions, on the contrary—along with occasional gold—metallic sulphides, normally absent from the reefs, make their appearance in small amounts, such as pyrrhotite, sphalerite, arsenopyrite, galena, etc., accompanied more rarely by the partial or complete replacement of the banket or quartzite by calcite, all of which speaks for a *later phase of metasomatism.* No other mineralised cross-connections having been recorded, it becomes remarkable, accepting the Hydrothermal Theory, that, in the general soaking which the entire system must have experienced, the gold-bringing solutions should everywhere have confined themselves to certain layers and never accidentally have transgressed across surfaces of stratification or followed planes of fracture, whereas, under the Placer Theory, the distribution of the pyrite and auriferous pyrite is precisely such as must have been *pre-determined* by the original spreading-out within the gritty sediments of detrital iron ores and alluvial gold. Furthermore, the majority of these intrusions are seemingly of *post-Transvaal age.* Had intrusion been the dominant factor, the bankets of the Vredefort area, pierced and metamorphosed by acid and basic matter, should have become highly mineralised.

The fact that from his elaborate study Fisher has had to conclude that the geological evidence favours the Placer but the microscopic the Hydrothermal theory, suggests that current views regarding " hydrothermal action " may be faulty. The writer feels that insufficient allowance has been made for the potency of normal ground-waters acting within a deforming mass of sediments buried beneath a pile of cooling lavas, with the development of crystalloblastic minerals from detrital materials containing trace elements including fine alluvial gold from distant sources.

Suggested Picture of Banket Formation.—The Witwatersrand System is built up of normal sediments—marine, fluviatile, and terrestrial—metamorphosed statically at first and dynamically thereafter

with the reconstitution of allogenic substances. Reconstruction started with burial of the materials, proceeded throughout their consolidation and was practically completed within Ventersdorp times, *i.e.* prior to most of the faulting and dyking. The conglomeratic zones on various horizons between base and summit were essentially "*placers*" carrying iron ores and gold, the latter finely divided because of its lengthy travel, though not excluding some detrital pyrite. Typical of such formations must have been liquid and gaseous hydrocarbons and sulphuretted hydrogen from organic matter and sulphur bacteria working on the sulphates contained in circulating waters, especially sea-water.

Increases in pressure and temperature brought about (*a*) the conversion of iron oxides into ferric sulphate, (*b*) the solution of the gold particles by the latter, (*c*) the reduction of the ferric sulphate to ferrous sulphate and sulphide, (*d*) the precipitation of the gold by the latter compounds aided by hydrocarbons, (*e*) the conversion of the whole of the iron ores into pyrite and the balance of the hydrocarbons into graphite, and (*f*) the recrystallisation of the silica and various silicate compounds with further rearrangement of those minerals as well as the gold under increased pressure, shearing, and heating. The fineness of the gold was due to recrystallisation of the metal in sub-capillary spaces, the responsible liquids never travelling far from the parent detrital grains. *Colloids* may have played a large part in the earlier stages of metasomatism. In shrinkage cracks and in fractures vein quartz was deposited, deriving its mineral largely from the enclosing or adjoining reefs. Subsequently intrusive dykes metamorphosed the country rock along contacts with development of chlorite and introduction of sulphides—and gold—and further mineral changes.

Accepting this view, it becomes unnecessary to postulate enormous amounts of sulphide- and gold-bearing solutions from unknown sources ascending along the pebble-layers—which, according to petrological evidence, must already have been partly, if not completely, cemented—or along hypothetical channels not yet disclosed by mining. The *Placer Theory* furthermore explains the phenomena observed in the other auriferous conglomerates on and outside the Rand, including particularly the Ventersdorp Contact Reef and those of the Black Reef Series, as well as the Tarkwa bankets of West Africa. Strikingly, where the Black Reef conglomerates are richest, as at Krugersdorp, Machavie, or Natal Spruit, the rocks lying unconformably underneath their base are *not* mineralised, while there are no convincing grounds for viewing those deposits as other than of placer origin (see p. 131). In the Tarkwa banket,[1] formed under surprisingly similar conditions, most of the detrital iron ores have remained unchanged, only a fraction

[1] *Gold Coast Geol. Survey*, Mem. 6, 1942.

thereof having been converted into pyrite with the recrystallisation of the detrital gold and the development of sericite and chloritoid.

Igneous Rocks in the System.—In addition to the interbedded volcanics of the Dominion Reef Series and those in the Government Reef, Jeppestown, and Bird Series there are many intrusions, mainly of basic rocks, but including types ranging from granite-porphyry and micro-granite and syenite through diorite, diabase, and gabbro to peridotite, particularly in the Lower Division.

The most abundant are quartz diabase and diabase, some marked by ilmenite and leucoxene, and next to them norite, especially among the slates, many forming sheets running parallel to the bedding, while others traverse the formation obliquely or in step-like fashion. By the upholders of the Infiltration Theory they are regarded as essentially responsible for the metasomatism of the banket. On the East Rand the Main Reef has been locally depressed through " bell-jar intrusions " of quartz dolerite of probably Ventersdorp age, the largest occupying an area 8 miles long between Springs and Marievale Mine.[1] Others again are seemingly related to the Bushveld Complex and are associated with granophyre-syntectics, as on Geduld. Dykes, some of late Karroo age, are also numerous and produce dislocation of the reefs ; they are hence a hindrance in mining, particularly as the strata adjacent are often shattered and water-bearing.

Pongola System.—Thus called by Humphrey,[2] this succession, probably 35,000 feet thick at most, makes a belt striking south-east from a point north of Amsterdam in the eastern Transvaal, passing Piet Retief, with extension into the adjoining part of Swaziland and expansion over the Pongola and Pivaan valleys, to contract beyond, with the Lower Division—there termed the " *Insuzi Series* " by J. S. Hedges—appearing from beneath Karroo beds in the deeply-cut gorges of the White Umfolozi, Buffalo, and Tugela rivers, reaching as far as Nkandhla. The beds are considerably folded with the north-west to south-east trend dominant, though with a cross-folding that has produced basin-structures.

The base is seen only in the south, resting with sedimentary contact on the (older) granite in the Insuzi Valley, and with marked discordance and conglomeratic base on schistose rocks at Mazabeku in the Buffalo Valley and at Nondweni. Elsewhere the (younger) granite is in intrusive relation with various horizons, with development of minerals such as andalusite, ottrelite, cyanite, etc.

The *Lower Division*, with a thickness in the centre of perhaps 19,000

[1] J. Ellis, *T.G.S.S.A.*, 1941, xliii, 127 ; 1945, xlvii, 143.

[2] W. A. Humphrey, *Union S.A.G.S. Ann. Rep. for* 1912, 99 ; *ibid., for* 1913, 61 ; *Expln. Sheet* 68, 1931 ; L. J. Krige, *Handb. Reg. Geol.*, 1929, vii, 7*a*, 42 ; A. L. du Toit, *Union S.A.G.S., Expln. Sheet* 109, 1931.

feet and in the south of 7000 feet, embraces from three to six groups of white, sugary to gritty quartzites with green phyllites, each followed by a thick group of amygdaloids (mostly andesites) with some tuffs, much cleaved and in places sheared into the state of chlorite schist. North of the Assegai River this division is represented by only one group of quartzites and one lava zone, probably the highest of them all. Intrusions of peridotite, gabbro, diorite, and granophyre are conspicuous.

The *Upper Division* is some 16,000 feet thick and restricted to the northern region with a small basal unconformity north of the Assegai, brought out between the Pivaan and Pongola rivers, where there is no difference in dip or strike, by a coarse conglomerate at the bottom of the upper formation. Essentially sedimentary and having only one zone of lavas, near the top, it consists of numerous quartzite members parted by bodies of slate and phyllite, which include several beds of red magnetic iron ore associated with jaspilite that may show contorted structure, particularly one in the lower part of the formation. Here and there, mostly along the eastern side of the lengthy belt, contact minerals have been produced by the transgressing (younger) granite.

Noteworthy are the occasional thin, well-defined conglomerates on various horizons, from the base of the Series upwards, some of which with pebbles of vein-quartz, striped and black cherts, green quartzite, etc., are pyritic and in places auriferous, for example at the low-grade Denny Dalton Mine north of Melmoth, the Dickson near Nkandhla, and in the Umhlatuzi Valley. The thick conglomerates on the Pongola are, however, poorly mineralised. Another peculiarity is the presence of faintly green quartzites showing typical sago-structure.

Along the Great Escarpment about Kaapsche Hoop south of the Godwan River, in the Elands River Valley and again from Sabie towards Graskop the Lower Pongola facies is reproduced in the " Godwan Series " several thousands of feet thick resting discordantly on the Fig Tree Series, in a belt one and a half miles wide, with dip of 20° W.N.W. and overlain unconformably by the Black Reef quartzites. Basic amygdaloids, tuffs, and agglomerates, with a variable quartzitic and sometimes conglomeratic base, dominate below, and hard feldspathic quartzites with some shales and a band of dolomite above.

When correlating these thick systems, the existence of rather similar pre- and post-Pongola granites invalidates the usual means for comparison. That the Barberton assemblages are older seems to be borne out by recent fieldwork. As set out by Humphrey long ago, and since confirmed, the Upper Pongola beds show remarkably close correspondences in general sequence and lithology with the *Lower Witwatersrand, and their equivalence seems almost assured.* The Lower Pongola, with its preponderating volcanic rocks, could then be

paralleled with the eruptive facies represented by the Dominion Reef Series of the Klerksdorp area. The Pongola and Witwatersrand outcrops are parted by a gap of only 75 miles. The correlation suggested would imply the existence in the eastern Transvaal of a *granitic phase younger than the "Old Granite,"* which observations in southern Swaziland, particularly by Hamilton,[1] support.

[1] G. N. G. Hamilton, *T.G.S.S.A.*, 1939, xli, 41.

CHAPTER VI

THE VENTERSDORP SYSTEM

Historical. Distribution. Thickness. Horizons. Volcanics. Sediments. Ventersdorp Contact Reef. Relation to Witwatersrand System. Economic. Koras Series. Konkip Series.

Historical.—In 1874 Stow [1] described the ancient lavas of Griqualand West, which pass beneath the "Campbell Rand Limestones," under the name of "The Amygdaloidal Rocks of Pniel" from the Mission Station of that name on the Vaal River close to the town of Barkly West. In the Transvaal, though much later, an identical volcanic formation was observed to intervene between the Witwatersrand beds and the Dolomite, one that came to be called the "Klipriversberg Amygdaloid" from the hills composed thereof immediately to the south of the Rand.

Subsequently these Volcanics were found to extend south-westwards from the latter almost uninterruptedly along the Vaal River to join with those at Pniel. On this account the name "Vaal River System" was conferred on them by Molengraaff in 1904; but Hatch [2] had already suggested the title of "Ventersdorp System," because of the development not only of lavas but also of associated sediments near the town of that name, and this designation has become standard.

In the Cape, while Stow's title was revived by the Geological Survey, the name Ventersdorp System was extended to embrace not only the Pniel volcanics and sediments, but certain older groups composed mainly of acid volcanic rocks, although they lay unconformably beneath the Pniel Series, as originally defined. Of such the "Zoetlief Series" has now been tentatively allotted to the basal division of the Witwatersrand, while the same may apply to the "Koras Series." The "Deweras Series" of Southern Rhodesia (p. 38) may on the contrary be of Ventersdorp age.

Distribution.—Though widely covered by beds belonging to the Transvaal and Karroo Systems, this formation is nevertheless well exposed over a very extensive region—from near Prieska in the south-west to beyond Johannesburg on the north-east, and from Genesa and Vliegepoort on the north-west to near Bethal and Theunissen—a territory 470 miles by 220 miles at least.

[1] G. W. Stow, *Q.J.G.S.*, 1874, 581.
[2] F. H. Hatch, *T.G.S.S.A.*, 1903, vi, 95.

Because of the great superficial development of *basic volcanic rocks* within that region the formation has been known as the " Amygdaloidal Diabase " or colloquially as the " Ventersdorp." The *sediments* and the *acid volcanics*, while of local importance, are areally limited, but underlie or are intercalated with the basic lavas over considerable tracts.

Appearing in the west from beneath the Dolomite of the Kaap Plateau the rocks are well exposed within the Vaal River basin between Prieska and Greylingstad, spreading northwards to Genesa, Mosita, and Mafeking, northwards to the Rand, and passing eastwards below the Karroo beds of the Orange Free State to form occasional inliers, as at Odendaalsrus and the Vredefort Dome, and as proved in borings about Leslie. They show up on the northern side of the Bushveld Basin and are probably represented in South-West Africa to the north of Aus, and in Southern Rhodesia.

Except in the main Witwatersrand Basin, *i.e.* between Roodepoort, Springs, Heidelberg, Greylingstad, and Vredefort, this important formation rests everywhere with definite *unconformity* upon the older systems, pebbles of which may be included in its conglomerates.

Thickness.—There are not many places where this can be accurately measured, for over wide areas the lavas make poor outcrops and reliance has to be placed on the occasional sediments. There are fully 5000 feet of lavas present on the Rand and near Fortuna Station in Heidelberg, where the volcanics are followed by a thick group of flagstones and conglomerates with quartzite pebbles, but exceed 6000 feet in places in Klerksdorp and Bothaville.[1] Around the Vredefort Dome, where all the formations have been overturned, a figure of 11,000 feet has been computed, though this value can be doubted.

Horizons.—In the continued search for extensions of the banket, for example in Klerksdorp, Bethal, and most of all in the Orange Free State, borehole after borehole is penetrating this formation, and the identification of lithological horizons having some lateral persistence becomes a matter of extreme importance. Provoking, however, is the marked variability in extent and thickness of such diverse types, their lenticular

[1] L. T. Nel, *Union S.A.G.S.*, 1935, Expln. Klerksdorp-Ventersdorp Geol. Map.

character on a large scale, and sometimes their transgressive behaviour, which have rendered surface mapping and borehole correlation difficult. In no field is this more marked than around Odendaalsrus. In the absence of sedimentary partings, dips in the lavas can commonly be made out from the contacts between successive flows, the rows of vesicles, or the central-banding in large agates. The presence of magnetic lavas, especially in the lower horizons, has proved of some value in geophysical prospecting (Krahmann and Beetz).

The System is largely of volcanic origin and composed of two main classes, though transitional kinds are also found :—

A. Volcanics—(1) Lavas, mostly basic, with some acid types ;
(2) Pyroclastics, such as volcanic breccias, agglomerates and tuffs, and

B. Sediments—(3) Conglomerates, quartzites, shales and cherts.

Such a sedimentary group tends to appear at the base, with others—frequently coarser—higher up.

The Volcanics.—These consist largely of rather uniform green diabasic lavas of fine to medium grain weathering with a thin dark-red crust. They are in places highly amygdaloidal with the vesicles filled in with quartz, chlorite, epidote, calcite, or chalcedony, the last often pink or bright vermilion, rather like sealing-wax in appearance. Porphyritic varieties with large greenish-yellow plagioclase feldspar crystals (albite or albite-oligoclase) up to three inches long are also well represented, particularly near the base, in the Rand, Klerksdorp, and Heidelberg areas and, though liable to be mistaken for intrusions, are flows, since they may be markedly vesicular. *The lavas are dominantly basaltic to andesitic in composition.*

Characteristic are *Volcanic Breccias* with angular to subangular fragments, ranging from extremely coarse and mostly unbedded and ill-sorted types—to which the name "boulder-beds" can be applied—to fine-grained banded tuffs, shales and cherts. The fragments consist largely of lavas of various kinds, tuffs, and older formations, including recognisable Witwatersrand rocks. Such have a wide distribution in Ventersdorp and Klerksdorp. When cleaved through pressure, such rocks tend to jut out from the ground in tooth-like masses, as, for example, in

the Bezuidenhout Valley in Johannesburg or to the north near Kempton Park (Plate V, 1).

Quartz porphyries and *Felsites*, associated with acid breccias and tuffs, are well represented in the south-western Transvaal, for example that flow capping the Platberg north of Klerksdorp and also present on the Townlands, where a borehole provides the following section (from the bottom upwards) [1] :—amygdaloid 1090 feet, tufaceous sediments 464 feet, amygdaloid 627 feet, volcanic conglomerate 100 feet, quartz porphyry 988 feet, banded tuff 6 feet, amygdaloid 792 feet.

Thin sections of the basic lavas show elongated crystals of plagioclase and rarely small porphyritic crystals of augite set in a felt-like aggregate of feldspar microlites and augite granules or some devitrified glass. Intense alteration is common with the feldspars replaced by quartz and chlorite and the augite by epidote, chlorite, and actinolite. The general type was originally a *basaltic andesite* (Analysis Nos. 13 and 14).

It had long been presumed that the magma was poured out from fissures, now represented by diabase dykes, but breccia-filled necks penetrate Witwatersrand beds to the west of Ventersdorp and Klerksdorp and between Greylingstad and Villiers, while sporadic shattering of the lavas, areas of coarse breccia enclosing in places large broken masses of Witwatersrand beds, and long belts of thick breccias north of Klerksdorp, all suggest extrusion from vents aligned along south-west trending fractures.

The tuffs and tufaceous sediments are usually dark bluish-grey, compact to stratified, made of rock fragments, quartz grains, feldspar crystals, and splinters of volcanic glass. Silicification may have converted them into cherts. The dolomitic limestones observed near Klerksdorp and Odendaalsrus may represent former calc-sinter deposits.[2]

The Makwassi Hills to the south of Wolmaransstad consist of pink, green, and red quartz porphyries with orthoclase phenocrysts sometimes over half an inch across. According to G. G. Holmes this rock is in places intrusive into the basic lavas. On the other hand, just north of Makwassi Station the porphyry appears to be overlain unconformably by a quartzite body and that in turn by Ventersdorp lavas. The porphyries do not closely resemble those of the Dominion Reef Series. These handsome and conspicuous rocks, which had attracted the attention of the early explorers such as Hübner and

[1] P. F. W. Beetz, *T.G.S.S.A.*, 1937, xxxix, 223.

[2] L. T. Nel, *Union S.A.G.S.*, 1935, Expl. Klerksdorp-Ventersdorp Geol. Map, 81.

Cohen, form a striking constituent of the Dwyka tillite throughout the Vaal River Valley and even farther towards the south-west.

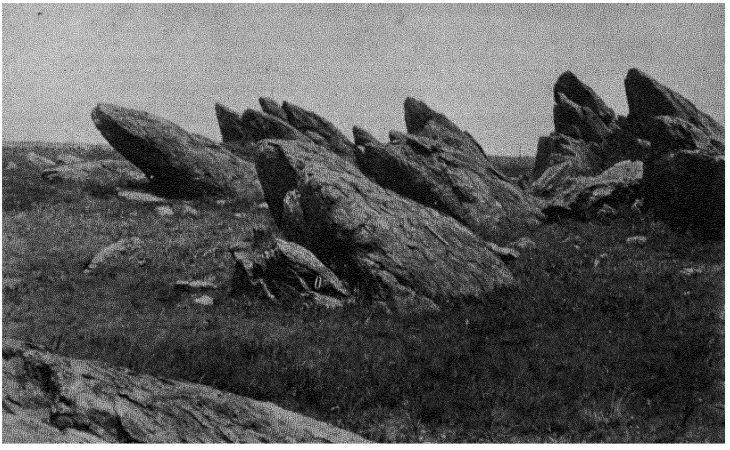
The Sediments.—Conglomerates, grits, feldspathic sandstones, and occasionally cherts and shales occur in bands that may be hundreds of feet thick and extend for miles, on various horizons —even high up—a common position being at the base of the system. Boulders, feet across, as well as pebbles may be present. Through the accession of volcanic detritus they pass into agglomerates and tuffs. Some of the quartzites are quite dark and occasionally black. On the Odendaalsrus Goldfields coarse ill-sorted cobble conglomerates with dark quartzitic matrix (colloquially termed "agglomerate-conglomerate")[1] attain thicknesses of up to 1675 feet, resting usually on the paler "basal quartzites" and overlain by volcanics; but these are probably of Elsburg age.

Such basal beds occur in the Cape at Omdraais Vlei in the Britstown district, at a few localities between that spot and Modder River Station, and have been pierced by the mine-shafts in Kimberley, where they are 400 feet thick—mostly medium-grained quartzites; pebbles of quartz porphyry can be found in them. In an important anticline at Pokwani and Taungs they are 600 feet thick, softer, with conglomerates towards their base, among which inclusions of banded ironstones are common. At Schweizer Reneke they reappear, being mostly quartzites that, resting on the Old Granite, dip eastwards beneath the lavas to emerge a little to the west of Wolmaransstad and stretch northwards in a belt for over 20 miles, where they lie unconformably on Lower Witwatersrand beds. Conglomerates are present at various points, for example on Lucas Kraal, Strydpoort, and Syfergat. Very coarse boulder-beds occur well up in the succession to the west of Ventersdorp, as at Makoks Kraal, and to the west of the village of Hartebeestfontein,[2] of which the bulk of the inclusions has been derived from the Lower Witwatersrand beds, including lumps of *banket*, some of which are auriferous. A body of conglomerates, with an identical assortment of pebbles set in a greenish, slaty matrix and passing upwards into grits, is known on Kromdraai north of Krugersdorp. In the town of Mafeking dark greenish, massive conglomerates and grits full of lumps of granite and diabase occur near the bottom of the normal series of basic amygdaloids.

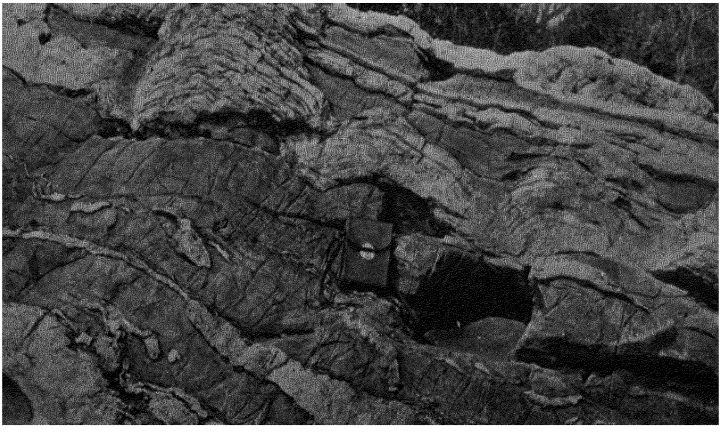
The Ventersdorp Contact Reef or "V.C.R."—This valuable conglomerate from 1 to 3 feet thick has been mined just south

[1] R. Borchers and G. V. White, *T.G.S.S.A.*, 1944, xlvi, 127.

[2] L. T. Nel, *Union S.A.G.S.*, 1935, Expln. Klerksdorp-Ventersdorp Geol. Map, 81.



1.—Outcrops of Ventersdorp diabase-breccia, south of Kempton Park Station, north-east of Johannesburg.



2.—Chert bands (lighter) in the Dolomite (darker), Uitloop near Potgietersrust, Transvaal.

[*Face page* 120

and west of Roodepoort, but particularly more to the south-west at the Venterspost Mine, where its study has proved highly instructive.[1] There it rests with angular discordance upon the Main Reef Series and its several bankets, the junction being uneven in places. The matrix is usually darkish, a peculiarity of this stratum and due presumably to volcanic ash, while the inclusions—mainly of vein quartz—are occasionally large and poorly rounded. The conglomerate may be overlain directly by the main lavas or by some transitional beds of tuff, etc., with very thin lava flows, just as recorded by Rogers[2] at the base of the Ventersdorp in Heidelberg. It has been proved on West Driefontein Mine. A similar V.C.R. is mined at Western Reefs, south of Klerksdorp, discordantly overlying quartzites and bankets belonging to the Gold Estates Reef Series (p. 72). There is no sign of it around the Vredefort Dome.

The evidence shows that *the Contact Reef must form the real stratigraphical base of the Ventersdorp System.* Traced eastwards, the break with the underlying strata becomes less obvious, so that through the Central and East Rand and on to Heidelberg it can be differentiated from the true Elsburg Series below only through being a rather dark pebbly zone, line of scattered pebbles, or band of grits giving low gold values. The relation to the Witwatersrand System may indeed be a *disconformable one*, like that between the Pretoria and Dolomite series (p. 138). The Contact Reef represents waste spread out over a wide plain during a period of *pre-Ventersdorp erosion*, and a part of its gold can definitely be traced to near-by Rand bankets, whence its high values when directly overlying such conglomerates. It will therefore represent a " fossil placer," its gold being partly alluvial and partly eluvial (de Kock). The mineralisation is like that of the Banket, namely pyrite, buckshot pyrite, pyrrhotite, etc., but specks of free gold are not unusual.

Relation to the Witwatersrand System.—There has been much discussion upon this question, which happens to be of particular importance in deep drilling. In the absence of contrary evidence, a pseudo-conformable relationship can be presumed beneath the basin situated between the Rand, Heidelberg, and the Vredefort

[1] W. P. de Kock, *T.G.S.S.A.*, 1941, xliii, 85.

[2] A. W. Rogers, *Union S.A.G.S.*, 1922, " The Geology of the Country around Heidelberg," 45.

Dome, and possibly even for some distance farther to the south. Outside that central region the Witwatersrand beds experienced tilting, faulting, and erosion to varying degrees during pre-Ventersdorp times, and the Ventersdorp rocks came to be deposited transgressively and discordantly across the full width of the older system, and in places upon the Old Granite.

Thus, east of the Rand, in the Devon-Leslie area, deep boring has proved to be resting upon an uneven surface of Lower Witwatersrand beds a great development of Ventersdorp rocks beginning with volcanic breccias, containing fragments of sediments and lavas, alternating with quartzites carrying occasional pebble-beds and pyritic bands overlain by the normal succession of amygdaloids with a zone of porphyritic lavas at its base. The whole assemblage is dipping mostly north-eastwards at low angles.[1] To the north of the Rand at Kempton Park the lavas lie on the granite, while to the west at Kromdraai (Swartkop) boulder-beds rest on granite and Witwatersrand strata. In Johannesburg the lavas, with a local patch of boulder-bearing sediments at their base, repose with *strong unconformity* upon the Hospital Hill Series on the western side of the Bezuidenhout Valley, while on the eastern side, resting discordantly on the Government Reef Series—of which they contain fragments—are the grits and conglomerates of Langerman's Kop, supposed to be Elsburg. Just 5 miles south the full sequence of the Rand can be observed.

In the Odendaalsrus area, as already noted (p. 97), the Ventersdorp rocks, inclined at relatively low angles apparently, transgress across various divisions of the Witwatersrand to rest on the Old Granite in the west (Weltevreden 190; Geduld 1272).

While the presence of contemporaneous volcanic flows on several horizons in the Witwatersrand and of sedimentary groups in the Ventersdorp would suggest the latter as the stratigraphical continuation of the former, the retention of *the two assemblages as distinct Systems* is eminently desirable and no attempt should be made to combine them under a single name.

Economic.—While various conglomerates in the sedimentary groups have been prospected, there has usually been insufficient concentration within them of detrital gold. The " Contact Reef " is, however, payable on and near Venterspost and at Western Reefs, and extensions of this horizon are confidently expected.

The Koras Series.[2]—About 50 miles up the Orange River from Upington, on Zaals Kop, there commences a strip of beds, mostly

[1] E. F. Fox, *T.G.S.S.A.*, 1940, xlii, 83.

[2] *Ann. Rep. G.C. for* 1907, 52-8; *for* 1909, 73.

volcanic, that continues north-westwards across the river into Gordonia. The formation rests on the Kheis quartzites and schists with marked unconformity, but is bounded in parts by faults of considerable magnitude, while there are also bodies of intrusive diabase which tend to obscure its relationships to the older formations.

In common with other series in which volcanics play an important rôle, the various groups of lavas, which differ in composition and character, do not persist regularly throughout the area, while the basal conglomerate, nowhere thick, is absent in places. The latter has an arkose matrix and contains rounded boulders up to over a foot across of Kheis quartzites and sometimes of granite.

The lavas are divisible into two groups : (1) *red quartz porphyries*, and (2) *red, purple, and blue amygdaloids*.

The former contain corroded phenocrysts of quartz and feldspar and crystals of feldspar with which quartz is intergrown, also small pyroxenes replaced by chlorite and epidote. The latter are mostly pyroxene andesites with much devitrified glass ; usually the larger crystals are replaced by alteration products. Augite and enstatite are present, the latter much epidotised. A characteristic feature of the lavas and also of the intrusive diabases as seen under the microscope is the presence of minute magnetite crystals arranged in long strings in the glassy base. The amygdales are of epidote or chalcedony or both, and the bright green colour of the former contrasts strikingly with the deep red of the matrix ; there are also tuffs and breccias.

The *upper part* of the series consists of red conglomerates, feldspathic sandstones and quartzites resting *unconformably* on the volcanic rocks and carrying pebbles, very largely of the andesitic lavas and quartz porphyries, but also of Kheis rocks, the inclusions being often closely packed together as in the (cretaceous) Enon Conglomerate ; they are often fractured and indented.

No boulders have been found that could have come from either the Matsap or the Transvaal System, wherefore the Koras is believed to be older than the Black Reef Series and possibly the equivalent of the Dominion Reef Series (p. 75).

The Konkip Series.—In South-West Africa on the Konkip River near Kunjas to the north of Aus there rests unconformably upon the gneiss a varied succession of beds given this name by Range in 1912.[1] They fringe the escarpment northwards as far as Tsaris and build the Nubis Mountains to the west, but are probably represented along the coast to the south of Lüderitz, as detailed on p. 166. Folded, they are overlain discordantly by the nearly horizontal Nama System and are

[1] P. Range, *Beitr. geol. Erfors. Deut. Schutz*, 1912, Heft 2, 13.

separable into three divisions, the structures being, according to Beetz,[1] rather involved. The lowest or Kunjas Series is a thin group of conglomerates followed by shales and limestones; the second or Sinclair Series consists mainly of volcanic rocks, both acid porphyries and basic lavas with conglomerates, breccias, and tuffs, while the third or Auborus Series consists of red rocks—coarse conglomerates and breccias at the base passing upwards into fine-grained sandstones. Beetz has reported the uppermost, which is over 2000 feet thick and unconformable to the older divisions, and manifestly of terrestrial origin, to be rather like some of the so-called Upper Nama to the north-east.

The second and third formations have, it will be observed, strong lithological resemblances to the Koras Series. It is not unlikely that several formations of widely different ages have been included under the name Konkip, just as under Koras or Ventersdorp.

Reference can here be made to the dark bluish, brownish, or violet quartz porphyry and granite-porphyry, older at least than the presumed Matsap beds, that build the Mabeleapudi and Kwebe Hills south of Lake Ngami and the Gubatsa and Goha Hills near the Linyanti (Chobe) River, all projecting from a sea of Kalahari Sand. An analysis is given by Rogers.[2]

[1] W. Beetz, *T.G.S.S.A.*, 1923, xxv, 23; *N. Jahr. f. Min., etc.*, B-Bd. 50, 1924, 414.

[2] *T.R.S.S.A.*, 1935, xxiii, 171.

CHAPTER VII

THE TRANSVAAL SYSTEM

Historical. Conditions of Deposition. Correlation. Transvaal. Northern Cape. South-West Africa and Namaqualand. South-western Cape. Younger Granites. Southern Rhodesia.

Historical.—(a) *In the Northern Cape* Dunn described the rocks of the Doornberg near Prieska in 1873 as " Namaqualand Schists (metamorphic)," while on his second Map (1875) they are indicated partly as " Namaqualand Schists " and partly as " Malmesbury Beds," and on his third Map (1887) as belonging to the " Lydenburg Beds," which comprised apparently the whole of the older rocks of the southern Transvaal.

In 1874 Stow, working in Griqualand West, called the lower division of limestones and quartzites the " *Campbell Rand Series* " and the upper one of magnetic jaspers the " *Griquatown Series,*" and was followed in 1899 by Rogers and Schwarz when dealing with the extensions of those rocks south of the Orange River—with the separation of the quartzite base of the dolomite group under the name of the " *Black Reef Series* " in conformity with current practice in the Transvaal. In 1905 Rogers termed the eruptive rocks forming a part of the Griquatown Series the " *Ongeluk Volcanic Series.*"

(b) *In the Transvaal* Penning, in dealing with the Lydenburg area in 1884, spoke of the " Megaliesberg Beds," which included the *Dolomite* under the name " Chalcedolite." In 1887 Dunn embraced all the ancient sediments as " Lydenburg Beds " on his Map. Schenck, in 1888, placed the latter, along with the Witwatersrand System, under the heading of the " Kapformation," and down to 1901 correlation with the Cape System was generally taken for granted.

In 1896 Draper classified this system into the *Dolomitic Limestone* (with the Black Reef Quartzite) and the *Gatsrand Beds*, while the following year Molengraaff introduced the alternative designation *Pretoria Beds*, the use of which has become general. In 1901 Molengraaff abandoned correlation with the Cape System, suggesting the name *Transvaal System*, forthwith accepted, though

later Hatch endeavoured to have the title Potchefstroom System substituted therefor. Since 1903 the work of the Geological Survey has led to the closer subdivision of the great thickness of strata involved and to the adoption of various local names for such groups and minor subdivisions; closer correlation with the equivalent but somewhat different facies of Griqualand West now became possible.

(c) The correlation of the Transvaal with the Nama System of South-West Africa (Chapter X), favoured by Range (1912), by Wagner (1916), and widely followed, is far from assured. At Upington a gap of only 90 miles separates the two formations, and such a view demands that within this distance the thick dolomite-jasper-lava phase of Griqualand West must have changed into the thin sandstone-red shale facies (Zwartmodder) of the eastern Nama, for which certain evidence suggests a younger age. Indeed, the Transvaal System shows far more resemblance to the pre-Nama *Stinkfontein-Kaigas* succession of the Lower Orange Valley, described in Sect. C, 1.

(d) In the *South-western Cape* investigations in the Olifants Valley have only recently disclosed a development of pre-Nama slaty and calcareous strata that appear to come closest to the type MALMESBURY BEDS as recorded by Dunn (1872) from the coastal districts towards the south. Although there is no strong indication that the latter must form the south-westerly representative of the Transvaal System, nor any assurance even that they may not be distinctly older, such Malmesbury beds can conveniently be dealt with here (Sect. D).

(e) In *Southern Rhodesia* are strata containing the thick limestones in which are situated the Sinoia Caves, termed the "Sinoia Series" by Mennell in 1910, but altered to "*Lomagundi System*" about 1919. Being of considerable thickness and having a wide distribution in Northern Rhodesia, correlation with the Transvaal System seemed the obvious course, though recent evidence has suggested a greater age (Sect. E).

Conditions of Deposition.—As set forth in Chapter XXI, much of what is now South Africa must during the Transvaal epoch have subsided beneath the ocean, within the waters of which calcareous rocks and shales were deposited. At a later stage marine gave way to estuarine, lacustrine, and perhaps even to

continental conditions. If one is correct, the final withdrawal of the ocean was westwards. With sedimentation spread over so vast a region, the presence of *local unconformities* and *changes of facies* could be anticipated, and are indeed found, so that exact agreement between the various subdivisions and phases is far from assured.

The primitive fossils found are mostly of *algal remains* in the limestones, but insufficient to date these deposits, though most of the strata are probably not younger than *late pre-Cambrian.*

Correlation Table.—On page 128 is given in tabular form the provisional classification of the sequences of the presumed Transvaal and Nama assemblages.

A. The Transvaal System in the Transvaal.—As shown in the table, the system is here triply divided in descending order into:

(3) The Pretoria Series—including the Rooiberg Group.
(2) The Dolomite.
(1) The Black Reef Series.

Distribution.—The main area occupied or else underlain by the system embraces the greater part of the central Transvaal and makes a *pear-shaped basin* stretching from the Drakensberg westwards, contracting in that direction and ending at Lobatsi in the Bechuanaland Protectorate, to start in a *second great basin* just beyond Kanya.

Within the main area, coincident with the "Bushveld," the strata are generally dipping inwards regularly beneath the cake of intrusive rocks by which they have become metamorphosed. On the south this great Basin has been bent over so as to connect with a subsidiary syncline situated between Krugersdorp, Heidelberg, and Potchefstroom, the southern side of which has been twisted up abruptly around the Parys Granite mass, beyond which it disappears beneath Karroo beds. Locally the structure is complex.

Relationships.—Previous to its deposition the older rocks had been worn down to an absolute plane upon which the *base of the system rests evenly and unconformably everywhere.* East of a line drawn from Mochudi to Bethal it reposes on the Witwatersrand or on older formations, but to the west thereof almost universally

	South-West Africa		Cape				Transvaal	Southern Rhodesia
	North	Centre & South	North West	South-West	South	Gordonia	Griqualand West & Bechuanaland	
Nama System	Quartzite	Fish River				Zwartmodder		
	Otavi Dolomite	Schwarzkalk						
	Nosib	Kuibis Nabas		Nieuwerust (Nuwerus) Basal Limestones				
Great Unconformity								
Transvaal System	"Folded Nama"?	Numees (Unconformity)		French Hoek?				
		Kaigas		Malmesbury	Cango		Griquatown (Upper, Middle (or Ongeluk), Lower)	Campbell Rand Limestones and Dolomites
		Stinkfontein						Black Reef
Lomagundi System							Pretoria (Rooiberg, Magaliesberg, Daspoort (and Ongeluk), Timeball Hill)	Dolomite
								Hunyani Range: Arkosic (Piriwiri Mountain Sandstone); Striped Slates
								Slates, Quartzites and Dolomites
								Basal Group
Great Unconformity								

on the Ventersdorp lavas, a relationship which holds good over the greater part of the Northern Cape region as well. While the Ventersdorp System did not experience very much disturbance prior to the deposition of the Black Reef quartzities, there are many places where a strong unconformity [1] can be seen, or proved by mapping.

The upper limit of the system, which, inclusive of the Rooiberg Group, but exclusive of intrusive sheets, attains a thickness of between 16,000 and 28,000 feet, is not known. In the central region there is everywhere an *intrusive contact with the Bushveld Igneous Complex*; otherwise it is overlain unconformably by Waterberg or Karroo beds.

1. The Black Reef Series

The thin, dark, and in places auriferous quartzites and small pebble conglomerates resting directly on the older systems about the Witwatersrand were thus referred to by Penning in 1891, and the name has consistently been applied to these basal siliceous beds in areas farther afield, even when the character of the rocks is somewhat different from that in the type locality.

From the East Rand westwards to Lichtenburg and southwards through Potchefstroom, Klerksdorp, and Vredefort the Black Reef is invariably thin, from 20 to 50 feet, insignificant in outcrop and composed of dense, hard, and rather dark quartzites, thickly bedded, but with some shales, particularly at the very top just beneath the Dolomite, certain of which may be appreciably magnetic.[2] It may have a conglomerate at the base or an arkose, the latter developed chiefly where it rests on granite, as to the south-west of Pretoria. The conglomerates are thin, impersistent, and variable in their position and character, and rather like the Rand bankets. The pebbles are small and consist mainly of quartz, together with some of quartzite, chert, and jasper. The matrix is dark-coloured, owing to its pyritic and chloritic constituents, whence the name "Black Reef."

Where the Black Reef reappears from beneath the Karroo beds to the east of Carolina, it is similar to that on the Rand, but

[1] A good example to the north-east of Johannesburg has been figured by Hatch and Corstorphine (*The Geology of South Africa*, Fig. 35, 1905), while the discordance is strikingly shown on Geological Survey Sheets 15 (Crocodile Pools) or 53 (Ventersdorp).

[2] To the north of Krugersdorp these have been styled the "Kromdraai Slates."

north of Sabie it thickens continuously to attain the remarkable maximum of 2500 feet in the Marieps Mountain north of Pilgrim's Rest [1] and occupies a breadth of several miles. By their hardness and low westerly dip the quartzites have come to form the top of the Great Escarpment of the Drakensberg, running north from the imposing Duivels Kantoor near Kaapsche Hoop, gashed through by the Olifants (Plate VI) and Blyde rivers. From the great ravine of the former the feature bends north-west, the strata acquiring a higher dip towards the Bushveld with local cross-foldings and the lofty range culminates in the eminences of the Wolkberg (6890 feet) and the Iron Crown (6964 feet), whence it is prolonged to the west-south-west in the Strydpoort Range, but makes a sudden northward inflection at Chunies Poort, passing to the north of Potgietersrust. From the Iron Crown the thickness decreases steadily, so that near Potgietersrust it has dwindled once more to 100 feet.

The quartzites weather in the peculiar and fantastic manner of the Table Mountain Sandstone, are vertically jointed and give rise to scenery of considerable grandeur, the rugged grey crags of the Escarpment contrasting with the rounded, grassy, and often forested granitic slopes of the "Low Veld" beneath. Concomitant with its great development in the east is its differentiation into three or even four lithological groups, namely a basal and an upper group of quartzites, fine to coarse, with some pebbly bands, a middle one of yellowish-grey shales and flagstones, and a group of similar beds at the top, transitional to the Dolomite.

In north-western Rustenburg this formation still remains less than 100 feet in thickness, consisting of pale yellowish rather feldspathic quartzites often with pebbly bands and sometimes with a bed of conglomerate at the base. The pebbles include felsite and basic amygdaloidal lavas from the underlying Ventersdorp beds. In the extreme west on the border of the Mafeking district the white quartzites and grits, which are here thin, are followed by over 100 feet of dark shales, while, where the belt enters the Cape Province, there is a thin contemporaneous basic lava between the shales and the overlying Dolomite.

Economic.—The pebbly seams at or near the base of the series are often very like those of the Rand in carrying pyrite in abundance,

[1] J. W. Brandt and H. D. le Roex, *T.G.S.S.A.*, 1945, xlvii, 79. (Most of the strata included in this thickness have been more recently separated from the Black Reef Series and assigned to a pre-Transvaal system.—Editor.)

View looking eastwards across the valley of the Blyde River, 2500 feet deep, towards Marieps Kop; Black Reef quartzites forming the Drakensberg Escarpment. The shaly zone in the Series is indicated by the bushy slopes on the conical peak on the left.

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gold, carbon, chromite, zircon, rutile, ilmenite, iridosmine, blende, chalcopyrite, galena, and sometimes diamond. The pyrite pellets and lumps in the conglomerate at the New Machavie on Eleazar, Klerksdorp, are apparently replacements of pebbles.[1] There were two generations of pyrite followed by blende, and that by gold. The gold is regarded by Frankel[2] as of placer origin—derived from nearby Rand bankets—but by Swiegers[3] as partly of hydrothermal origin.

2. The Dolomite

Distribution. Thickness. Lithology. Banded Ironstones. Origin. Weathering. Water Supplies. Economic.

Distribution.—This massive calcareous formation, always spoken of as "The Dolomite," follows *conformably* upon the Black Reef Series, sometimes with a sharp boundary, sometimes by means of passage beds. It encircles the Bushveld region, making an outcrop from 4 to 12 miles wide usually, though broadening very extensively in Marico and Lichtenburg and carrying many "pans," but is obscured by Waterberg beds in the Nylstroom district and by an extensive covering of Karroo strata between Delmas and Carolina. Boreholes prove the southern edge of the "basin" to curve through Eendracht near Leslie past Trichard, the Dolomite having been struck at 794 feet at Bethal and the Old Granite at 869 feet on Beginsel 25 miles to the south-west.

At a few places in the Bushveld more or less isolated strips are found occupying abnormal positions enveloped by the Red Granite, for instance those on the Crocodile River west of Boshoffs Berg, immediately to the west of Warmbaths and at the junction of the Elands with the Olifants River. Between Randfontein and Ventersdorp the central region is all but separated from the large auxiliary basin of the Potchefstroom and Vereeniging districts by a narrow anticline of Black Reef quartzites and the Dolomite sends one long arm in a south-westerly direction down the Mooi River and across the Vaal River to Vierfontein, while the other follows the curve of the Klip River to Vereeniging, with a subsidiary basin between Germiston and Heidelberg.

[1] L. T. Nel, *Union S.A.G.S.*, 1935, Expln. Klerksdorp-Ventersdorp area, 88; J. U. Swiegers, *T.G.S.S.A.*, 1939, xli, 177.
[2] J. J. Frankel, *T.G.S.S.A.*, 1941, xliii, 1.
[3] J. U. Swiegers, *ibid.*, 1940, xlii, 35.

The southern side of the Potchefstroom basin has been twisted up in the curious dome of the Parys granite region, and the Dolomite, making a regular semicircle and standing on edge or even overturned, passes at both ends beneath the Karroo. Borings at Kroonstad have proved it at a depth of a thousand feet—the southernmost point at which it is known in the Orange Free State. Of importance in mining are the Dolomite " basins " of the East and Far West Rand, where its fissured and water-bearing nature has led to difficulties in sinking and to high pumping costs.

Thickness.—With a maximum thickness of fully 7000 feet in north-west Rustenburg, it is 4700 feet at Ireton, exceeds 4000 feet near Lichtenburg and is from 3500 to 4000 feet in the Potchefstroom-Rand-Pretoria area and again to the south-east of Potgietersrust. Southwards through the Lydenburg district the formation thins remarkably, more especially from the Godwan River onwards, for it is 1700 feet at Pilgrims Rest, 1000 feet at Sabie, and a mere 120 feet where last seen to the east of Carolina.

Lithology.—In spite of its remarkable thickness, the formation is composed almost entirely of well-bedded magnesian limestones with subordinate bands of chert; exceptions will be mentioned below. The limestones occur in rather solid beds, though on weathered surfaces a conspicuous banding often shows up, while the layers are quite commonly wavy or finely crinkled with very occasional ripple-marks; bands showing oölitic structures are sometimes present. The rock is blue-grey, compact, or minutely crystalline, but pink, red, and purple varieties can be seen at both Chunies Poort and Vliege Poort. Chemical examination proves the bulk to be dolomitic limestones, while thin sections under the microscope display small crystals of dolomite set in a groundmass of calcite. Small amounts of carbonates of iron and manganese are characteristic, as shown by the following analysis[1]:— $CaCO_3$ 48·4 per cent., $MgCO_3$ 40·6 per cent., $FeCO_3$ 1·8 per cent., $MnCO_3$ 2·9 per cent., SiO_2 and silicates 5·2 per cent. The rock is often much veined by calcite. The specific gravity is 2·85 on the average. Metamorphism by the Bushveld Complex has developed silicates such as tremolite, actinolite, etc.

The white, grey, or black chert which is so characteristic is

[1] Based on ten fairly consistent commercial analyses quoted by T. N. Leslie, *S.A.J.S.*, 1924, xxi, 161.

present both as layers following the bedding—from films up to bands and lenses many feet in thickness—and as large irregular masses or veins ; not uncommonly the dolomite is seamed through by threads of chert or cherty quartz (Plate V, 2). Generally the chert is more abundant in the upper part of the formation. At the summit shales and banded ironstones occur transitional to the Pretoria Series, to be referred to under that heading.

Occasionally layers of dark carbonaceous shale a foot or more thick are found in the Dolomite, but at Pilgrims Rest there is a band of greyish quartzite overlain by some shale in the lower third of the formation known as the Blyde River Quartzite, while two thin, higher zones of shale are also present. In the inlier traversed by the Crocodile River to the west of Boshoffs Berg there is a zone fully 100 feet thick of white quartzites and altered shales some 800 feet below the top of the group.

The Banded Ironstone Horizon.—Absent along the southern edge of the Bushveld, there appear at the top of the Dolomite in the west, north, and north-east certain ferruginous strata which can more properly be grouped with the Dolomite than with the Pretoria beds, since the conglomeratic zone taken as the base of the latter overlies these ferruginous rocks. A band of dolomite may even intervene as at Thabazimbi, and at Penge (Lydenburg).

A few miles to the north-west of Zeerust the cherty rocks, which elsewhere make the top of the Dolomite, become ferruginous and pass by degrees into cherty quartzites and brown and black banded ironstones. Owing to their hardness they form the Linokana Hills, which trend north-westwards to the Bechuanaland border. Along the north of the Dwarsberg this zone consists of shales, which on approaching the Marico River become ferruginous. From a point due north of the Pilansberg they grade into banded ironstones and jaspers and thicken, so that on the Crocodile River they attain a value of 700-800 feet and contain important deposits of *hæmatite ores* (p. 527), mined at Thabazimbi. Owing to duplication through thrusting they make a double range where cut through by the river on Vliege Poort. The chain is continued eastwards in the thrust-area of Gatkop and the Sand River, where they are between 150 and 250 feet thick, while they reappear just west of Warmbaths.

From Chunies Poort they extend south-eastwards in an arc to the Steelpoort River, locally crumpled, and carrying seams of blue and white asbestos (p. 496). Regarding the nature and origin of these rocks see p. 158.

Origin of the Dolomite.—Oölitic and pisolitic varieties are common, regarding which R. B. Young[1] has shown that these spherulitic bodies possess a radiate structure and were originally composed of aragonite, but have often been changed to a mixture of calcite and dolomite or dolomite alone, while sometimes the calcite matrix may have been replaced by silica, resulting in an oölitic chert. Not improbably the aragonite was directly precipitated from the calcium sulphate contained in sea-water by the action of ammonium carbonate from the decomposition of organisms. Silicification has converted limestones into rocks that possess the appearance and composition of quartzites, which helps to support the view that much of the chert, present in beds up to 100 feet or more in thickness, as well as that crossing the bedding, is of secondary origin. Some of the cherty matter has doubtless originated from the siliceous skeletons of sponges and diatoms. Carbonaceous matter is sometimes present as layers, veinlets, or replacements of limestone, derived probably from original hydrocarbons.

Young has furthermore described *stromatolitic* or algal limestones in which successive layers show the spaces between these branching structures filled up with, and the layer covered by, fine calcareous sand with occasional flat limestone " biscuits " like those known today from the Bahama Islands.

There can be no doubt that the Dolomite both in the Transvaal and Cape is a *marine deposit* formed in the open sea away from land, as the absence of coarse sediments testifies, but probably at no great depth, as the oölitic bands, intra-formational conglomerates, and ripple-marked surfaces would suggest, or even exposed occasionally at low-tide.[2] The characteristic manganese content at once invites comparison with the existing oceanic clays. The important question of the dolomitisation of the limestones, the other kindred problems and the origin of the Dolomite have been well discussed by C. Baring Horwood (*The Dolomite Formation of the Transvaal*, 1905).

Save for stromatolitic structures comparable with *Collenia*, *Gymnosolen*, etc., and a fragment possibly of a brachiopod from Schmidt's Drift, no identifiable fossils have yet been discovered, and it must be concluded that the Dolomite is most probably of PRE-CAMBRIAN AGE.

Weathering.—The fresh blue-grey rock soon acquires on exposure a dull leaden appearance and ultimately a deep brown crust, curiously wrinkled, corrugated or channelled, which from its resemblance to an elephant's hide has earned for it the Dutch

[1] *T.G.S.S.A.*, 1906, ix, 57; 1928, xxxi, 157; 1933, xxxv, 29; 1935, xxxvii, 153, 163. *Ann. Rep. G.C. for* 1906, 24.

[2] R. B. Young, *T.G.S.S.A.*, 1934, xxxvi, 121; 1941, xliii, 17 and 23; 1943, xlvi, 91; 1946, xlviii, 43.

name of Olifantklip ("elephant rock"). The external chocolate colour is due to the presence of oxides of manganese and iron from the oxidation of the small quantities of the carbonates of those elements in the dolomite. Indeed, in a number of places, *e.g.* west of Krugersdorp, there has been such a concentration of manganese oxide in the surface soil that the material is worked as a manganese ore (pyrolusite). Cavities filled with wad are not uncommonly met with in shaft sinking or in boring.

By the removal of the soluble calcareous portions the siliceous or cherty nodules and ribs tend to stand out from the surface. Like other limestone formations the world over, solution has played a very important part in the evolution of the surface configuration. Over the flatter ground "sink-holes" or "swallow-holes" are numerous, leading away into the depths, and sometimes contain standing water, as in the remarkable "Wondergat" some distance to the east of Mafeking. There are indeed quite a number of caves in this formation, for example at Wonderfontein near Oberholtzer Station, at Sterkfontein close to Krugersdorp, those between Koster and Ventersdorp, etc. Solution of the rock in depth has in places led to the collapse into such hollows of patches of Coal Measures, *e.g.* Delmas, Welgedacht east of Springs, Syferfontein and Zuurbekom west of Johannesburg, and of the Griquatown jaspers on a large scale at Postmasburg (p. 159).

Over wide areas the formation is hidden by a deep, red, sandy "residual" soil (p. 484) full of lumps of the insoluble chert, blackened by a coating of manganese oxide, below which come angular chert rubble, masses of "rottenstone," and shattered beds of chert, the whole often exceeding 100 feet in depth, but reaching the amazing figure of 450 feet at the Pumping Station at Zuurbekom. In the drier region of the west, in Lichtenburg, Marico, and over the Kaap Plateau, the formation is widely covered by porous calcareous tufa (see p. 446).

Water Supplies.—The abundance of joints and solution-channels enables great volumes of water to be held in the Dolomite, and all the large springs of the Transvaal issue from it, for example the Aapies at Pretoria, Steenkoppies (the "Eye" of the Magalies River), Klerkskraal (the "Eye" of the Mooi River), Turffontein, and Gerhardminnebron near Frederikstad, Ventersdorp, the "Eye" of the Marico River, and the Kuruman Spring in the Cape. The water gushes forth from that at Gerhard-

minnebron at the rate of between 21 and 26 cubic feet per second, removing in solution between 10 and 13 tons of dolomite per diem.

Excepting for such solution channels following joints and bedding planes the rock itself is compact and impervious, wherefore the Dolomite is one of the most unsatisfactory formations for water-boring.

Economic.—The dolomitic *lime* (blue lime) burnt in the Union is furnished by this formation, which is indirectly the source of the calcareous tufa used in the production of white lime and cement.

The *gold* veins of the Malmani and Pilgrim's Rest areas and the *lead* and *zinc* deposits of the Marico district are referred to in Chapter XX. *Vanadium* ores and *fluorite* (fluorspar) occur, though the output of the latter has much decreased lately. Superficial beds carrying secondary manganese ore (*pyrolusite*) exist to the south-west and north-west of Krugersdorp.

3. The Pretoria Series, including the Rooiberg Group

General. Stratigraphy. Subdivisions. Timeball Hill Group. Daspoort Group. Ongeluk Volcanics. Magaliesberg Group. Rooiberg Group. Economics.

General.—Following regularly upon the Dolomite—or upon the Banded Ironstones at the top of the latter, wherever such are represented—these beds make a broad ring inside that formed by the Dolomite in the central region of the Transvaal, attaining a thickness of from 14,000 to 24,000 feet exclusive of igneous intrusions (Figs. 22 and 23) and spreading out widely in the east.

There is a general dip of from ten to thirty-five degrees inwards towards the centre of the "basin," in which direction the strata come to be overlain or replaced by the norite and red granite of the Bushveld Complex. These plutonic intrusions were introduced near the top of the series—near the summit of the Magaliesberg quartzites over a very large area. Away from the Complex the Pretoria Series has been extensively invaded by thick sheets of diabase, that follow more or less the bedding-planes, and under the influence of these and of the central Complex the beds have been much altered. Soft shales have, for example, been converted into thoroughly crystalline rocks, whereupon the original character of the sediments concerned can only be arrived at indirectly, or through finding the same horizon not too far away in a less or hardly altered condition (see p. 140).

In addition to the main area constituted by the Bushveld, this series, following on the Dolomite, appears again to the south of Johannesburg in the broad shallow basin of the Gatsrand, which extends southwestwards to beyond Potchefstroom. On its southern side, approaching the Vaal River, the strata have, along with the Dolomite etc., been upturned around the Parys granite. Diabase intrusions are equally characteristic of this area.

Stratigraphy.—Excluding the topmost or Rooiberg Group the series is composed of *six members*—three thick, typically argillaceous stages and three thinner, quartzose ones; and despite the huge area concerned this sixfold succession has, with certain lateral changes in facies, been satisfactorily mapped right through the Transvaal.

The dependence of topography upon geology is never better exemplified than with this formation. The shaly groups with their associated diabases tend to occupy the lower ground, while the quartzites stand out in ridges, running regularly for miles. Nothing indeed is so striking to the observer as these huge parallel quartzite walls vanishing into the distance, with rugged scarps facing outwards and long dip-slopes descending evenly on the opposite sides. The rivers have broken through these ranges in narrow and picturesque gaps, for example Hartebeest Poort and

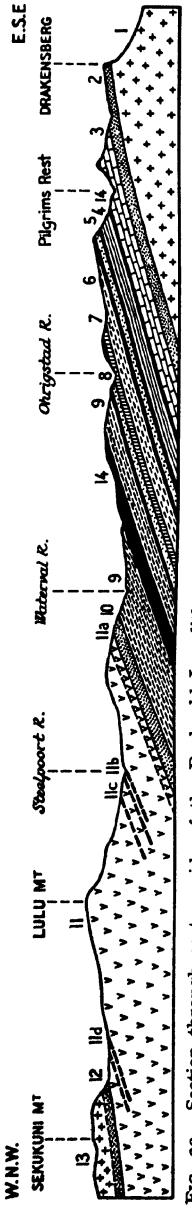


FIG. 22.—Section through eastern side of the Bushveld Lopolith; length 70 miles. 1, Old Granite; 2, Black Reef quartzites; 3, Dolomite; 4, Timeball Hill Shales; 5, Timeball Hill Quartzites; 6, Daspoort Shales; 7, Ongeluk Volcanics; 8, Daspoort Quartzites; 9, Magaliesberg Shales; 10, Magaliesberg Quartzites; 11, Bushveld Norite (11a, Diabasic Base; 11b, Chromitite Horizon; 11c, Platiniferous Horizon; 11d, Magnetite Horizon); 12, Recrystallised ("Rooiberg") Quartzites; 13, Bushveld Red Granite; 14 (*black*), Diabase.

Vliege Poort on the Crocodile; and it is generally by means of these occasional passages that access to the next parallel valley is provided (Plate VII, 1).

In addition to sediments there are also four horizons of *contemporaneous volcanic rocks*, two of which are widespread and the other two localised. In describing each of these several subdivisions and its lithological and other variations, the ring-like area of the Bushveld will be discussed in a *clock-wise direction*, starting with the Pretoria district. The changes effected through the metamorphic action of the Bushveld Complex will be discussed after the account of the latter.

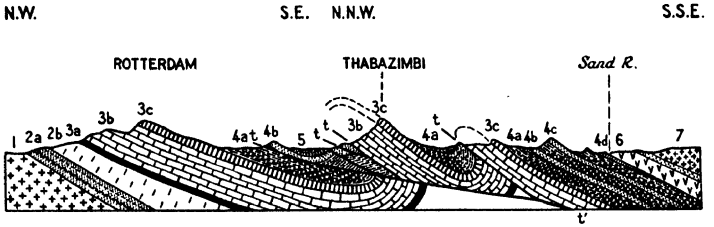


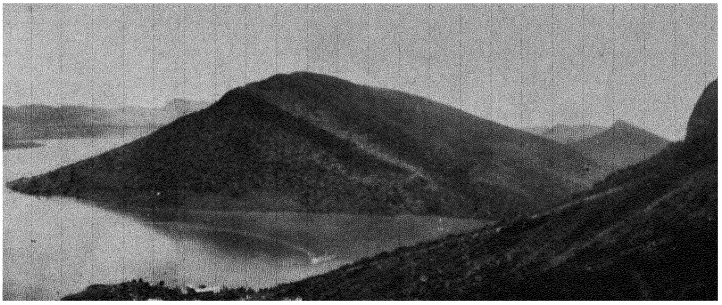
FIG. 23.—Section across the north-western edge of the Bushveld Basin at the Thabazimbi Iron Mines, length 15 miles (*in part from* Boardman). 1, Old Granite; 2a, Witwatersrand (quartzites and shales); 2b, Ventersdorp (acid lavas); 3a, Black Reef; 3b, Dolomite; 3c, Banded Ironstones; 4a, Pretoria Shales; 4b, 4c, 4d, Pretoria Quartzites; 5, Waterberg Sandstone; 6, Bushveld Norite; 7, Red Granite; t-t', Thrust-plane.

Subdivisions.—The table on p. 139 shows the subdivisions that have been established.

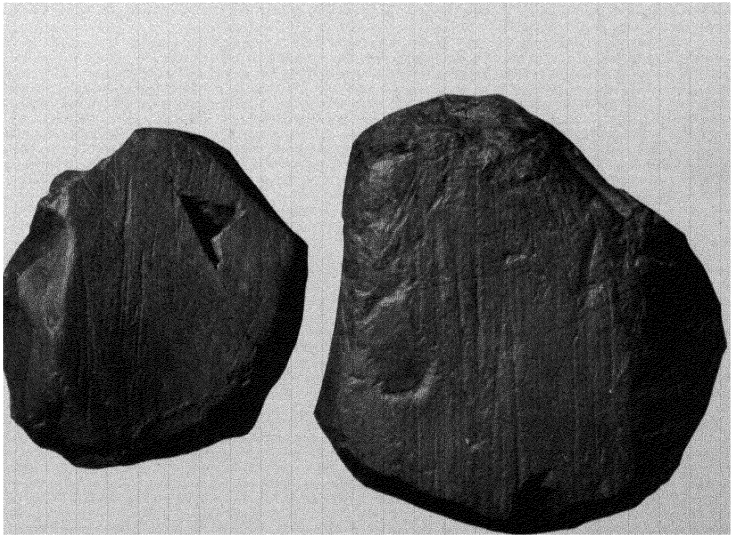
(A) *Timeball Hill Group—Base of the Pretoria Series.*—While the succession from the Dolomite upwards is apparently unbroken in certain areas, a thin but persistent horizon of *chert-breccia* or *chert-conglomerate* is developed over much of the Transvaal, indicating a brief period during which the Dolomite was subjected to some erosion. There is almost invariably just above this horizon an abrupt change to shale, wherefore this band constitutes an admirable divisional plane within the Transvaal System.

By selecting it as the base of the Pretoria Series, the banded ironstones mentioned earlier have, if not altogether appropriately, to be included with the Dolomite.

The characters of this pebbly band suggest a beach deposit: one produced during the temporary emergence and erosion not only of the



1.—The east-west trending Magaliesberg Range cut through by the Crocodile River now converted into the Hartebeestpoort Dam. The Magaliesberg Quartzites dip northwards and have been dropped down between faults to make the block in the centre. The slopes in the foreground are formed by the Magaliesberg Shales and intrusive diabase, while the Daspoort Quartzites produce the dip-slopes on the extreme left.



2.—Striated chert pebbles from the Griquatown Tillite.

[*Face page* 138

Dolomite but of the Black Reef quartzites as well; after that, under the new and presumably revolutionised geographical conditions, argillaceous instead of calcareous muds came to be laid down.

Basal Conglomerate.—While varying in its nature from point to point, as would be expected from its presumed mode of origin, the band is generally extremely hard, greyish, composed of angular to sub-angular lumps of white, grey, or bluish chert set in a matrix that is sometimes quartzitic and gritty, but more often flinty; pebbles of vein-quartz and of vitreous quartzite are not uncommonly present as well. While attaining a thickness of 80 feet, its general value is usually from a few up to 20 feet but, on account of its intense hardness and the fact that it is succeeded by soft shales, the stratum not unusually makes an easily traceable outcrop.

Group	Stage	Thickness in Feet*	Volcanic Phase	Thickness in Feet
4. Rooiberg	(*n*) Sandstones and Shales	0–2000	..	..
	(*m*) ..	..	Rooiberg Felsites	1–8000
3. Magaliesberg	(*l*) ..	..	Dullstroom Volcanics	0–1000
	(*k*) Magaliesberg Quartzites	2000	..	..
	(*j*) Magaliesberg Shales	2–5000 (?)	..	..
	(*i*) ..	..	Machadodorp Tuffs	0–600
	(*h*) Magaliesberg Shales	2000	..	..
2. Daspoort	(*g*) Daspoort Quartzites	80–250	..	..
	(*f*) Daspoort Shales	..	..	..
	(*e*) ..	..	Ongeluk Volcanics	0–5000
	(*d*) Daspoort Shales	500–2000	..	..
1. Timeball Hill	(*c*) Timeball Hill Quartzites	80–500	..	..
	(*b*) Timeball Hill Shales	600–3000	..	..
	(*a*) Basal Conglomerate	3–80	..	..

* Excluding intrusive sills.

In the Pretoria district it is more like a brecciated chert and therefore difficult to distinguish from the top of the Dolomite; in southern Rustenburg the matrix is somewhat ferruginous. To the north of the Dwarsberg the zone attains to 50 feet, resting on shales, but at Vliege Poort on the Crocodile, where it is 20 feet thick, it reposes on the banded ironstones and is followed by shales altered to chiastolite hornfels; here it carries flattened or sub-angular inclusions mainly of greyish chert.

Near Zebedela's Location in the north-east it thickens to as much as 80 feet and has pebbles of vitreous quartzite and of chert set in a scanty, hard matrix. Farther to the south it is known as " Bevet's

Conglomerate," being a very conspicuous horizon in spite of its small thickness (4 to 10 feet). In the Olifants River area it rests on banded ferruginous slates, but in the Pilgrims Rest neighbourhood directly on the Dolomite. In the extreme south the conglomeratic portion is confined to the top of the zone, which is known locally as the Rooi Hoogte Quartzite and which is from 3 to 20 feet thick, reposing either on thin shales or on the Dolomite. Along the northern side of the Gatsrand in Potchefstroom this zone is developed at intervals, while a little to the east of Frederikstad there is a poorly bedded greenish sandstone in this position with well-worn pebbles.

The Timeball Hill Shales.—In their typical development within the Pretoria district these consist of from 600 to 800 feet of soft and well-bedded shales and flagstones weathering cream, yellow or red, but grey or dark-blue when fresh, as, for example, in quarries at the Capital—the source of its paving flags. Elsewhere they are much thicker, while in many places they are metamorphosed.

The stage thickens westwards to about 1200 feet on the Marico River and from thence onwards exhibits considerable metamorphism with the development of chiastolite and andalusite. Towards Zeerust the shales at their base become more and more ferruginous, although still soft. Along the Dwarsberg they are not particularly altered, but become much more so in the neighbourhood of Vliege Poort.

To the east and south-east of Potgietersrust they are about 1500 feet thick and are soft, bluish, and unaltered, while similar characters hold from Pilgrims Rest to Carolina; but between Zebedela's Location and the Olifants River we find a remarkable change not only in thickness—for the stage swells out to about 3000 feet—but in facies, for the shales pass gradually into thinly-bedded ferruginous quartzites, the transition affecting the lower zones more particularly. This transformation attains to its maximum in the neighbourhood of the Malips River; in places contact minerals such as staurolite are found.

In the Klip River-Potchefstroom area the stage is about 1000 feet thick and quite normal in character, but from a point just to the north-west of Krugersdorp westwards through Zeerust to the Bechuanaland border a thin siliceous horizon is developed in the lowest fourth of the shales, called the "Polo Ground Quartzite," from 20 to 40 feet in thickness.

The Timeball Hill Quartzites.—Taking its name from the Timeball Hill overlooking the Pretoria Railway Station, this stage embraces not a single unit, but several bands of fine- to medium-grained quartzites parted by a good deal of greenish

flagstones and shale, the total thickness of the assemblage being about 250 feet. Not far above the base crops out a conspicuous and highly characteristic band of siliceous, oölitic iron-ore, that helps to distinguish this stage from the two higher quartzite subdivisions (see pp. 143, 145); it is persistent from Delmas to near Zeerust though lower in grade elsewhere. Owing to its compound nature this quartzitic stage rarely makes so conspicuous a ridge as the other two quartzites.

Followed westwards, the quartzitic bands run together to form a single zone near Zeerust 60 to 80 feet thick, a bit ferruginous near the base; but beyond this point a double outcrop is produced, of white or red sugary quartzites parted by shales, a character which continues into the Dwarsberg, as, for example, at Apjaters Kop, where the lower ferruginous band is conspicuous; towards the Crocodile River the stage is concealed over great distances. From Potgietersrust to beyond Chunies Poort we find a single non-ferruginous quartzite about 120 feet thick, increasing to 180 feet at Ohrigstad, after which it splits into two, and through Lydenburg into as many as five quartzites with the ferruginous horizon near the base, but coming together again in the direction of Carolina.

In the Klip River-Potchefstroom area this stage is very conspicuous, building up the long arc of the Gatsrand overlooking the dolomite flats to the north.

(B) *The Daspoort Group—The Daspoort Shales.*—Resembling when unaltered, as in the Pretoria and Potchefstroom districts, those of the Timeball Hill group, they can always be identified in the field by the presence, two-thirds up in the sequence, or nearer the top, of a thick body of contemporaneous lavas—the *Ongeluk Volcanics*—below which there show up in places the *Ongeluk Quartzite* and locally the *Glacial Band.* A single ferruginous bed or a series of them generally appears in the shales overlying the volcanics. The total thickness of the argillaceous strata ranges between 500 and 2000 feet.

A thin bed of argillaceous, oölitic (clayband) ironstone, dark greenish when fresh but brown at the outcrop, is present at the very base in the town of Pretoria, where the seam has been smelted for iron (see p. 528) West of the Crocodile River the shales manifest alteration, a character which grows more intense towards the west, so markedly that the upper shales stand up to form the Witwatersberg to the south of Hekpoort. The iron-ore horizon of Meintjes Kop, Pretoria, expands to make a series of black flagstones built up of quartz and magnetite, which passes into " andalusite-fels " in the direction of Zeerust, a

condition that persists into and along the north-western side of the basin to a point opposite the Pilansberg, where the beds are cut out by the transgressive norite. To the south-east of Potgietersrust a single body of somewhat altered slates is found (the Ongeluk lavas being missing) which near the Malips River have been intensely metamorphosed into the condition of micaceous schists. The volcanics appear near the Olifants River and continue southwards to Belfast; in this direction the upper shales thin out, so that to the south of Ohrigstad the Daspoort quartzites come to rest directly or almost so upon the top of the Ongeluk lavas.

The Ongeluk Quartzite and the Glacial Zone.—Close to Magaliesberg Station a thin band is found immediately underlying the Ongeluk volcanics, persistent from the Elands River to a point north of Zeerust and conspicuous because of its quartzitic and conglomeratic nature. Possessing a thickness of from 10 to 20 feet, it is greenish-grey and contains an intensely hard band crowded with small well-rounded or flattened pebbles of light-coloured quartzite, vein-quartz, and various kinds of cherty or jaspery rocks. In the Pilgrims Rest area an identical greenish pebbly quartzite makes its appearance in a similar apposition, for instance at Ohrigstad, wherefore the horizon is known as the "*Ongeluk Quartzite.*"

While no undoubtedly glaciated inclusions have so far been discovered within this particular band, the latter is at Magaliesberg Station underlain by some 50 feet of a green, gritty, but unstratified rock with small isolated pebbles, some of which exhibit scratches ascribable to glacial action. The same material reappears just south of Kraalkop on the Johannesburg-Potchefstroom road. To the south-east of Pretoria, on the farms Rietfontein (448) and Rietvlei (221), and traceable to the south-east, this zone attains a thickness of over 250 feet, both underlain and overlain by ordinary shales and the last by the volcanics. It has the unbedded character of a tillite, is crossed by a strong cleavage that does not affect the enclosing shales above and below, and is a gritty mudstone, pink at the surface, though bluish when fresh, containing small inclusions disposed irregularly and sparsely through the mass. These are always small, rarely over 6 inches in length, and include types such as could have been derived from the Barberton, Witwatersrand, Black Reef, and Dolomite formations. The harder pebbles such as vein-quartz, quartzite, and grey or banded chert are free of markings, but the softer types such as quartz porphyry sometimes display ice-scratches. By reason of their dominantly hard nature and well-worn but flattened or bun-shaped outlines, it is likely that the pebbles were beach-gravels picked up and transported by ice; there is no trace of a glaciated floor and the zone certainly does not represent a ground-moraine.

The distribution of this deposit has not been worked out, but some specimens collected from near Ohrigstad suggest its possible occurrence in that region. Taken in conjunction with the volcanic division almost immediately overlying, there is no doubt as to its equivalence with the glacial horizon at the top of the Lower Griquatown beds of the Cape (see p. 160).

The Ongeluk Volcanics.—So close is the correspondence lithologically and stratigraphically with the Ongeluk volcanic division of the Griquatown Series that there has been no hesitation in correlating them with the latter.

The band commences in the north-east near the Olifants River and runs almost due south, gradually thickening, so that where it crosses the Delagoa Bay Railway it has a value of about 800 feet. Disappearing beneath the Karroo beds to the south of Belfast, it emerges on the Wilge River to the south of Witbank, passes through the town of Pretoria, builds up the Schurvebergen to the north of the Zeerust railway, and extends north-westwards to the Bechuanaland border. Along the north-western side of the basin it can be traced to a point opposite the Pilansberg, where it is cut out by the igneous complex, but is thinner on this side. The division is fully developed throughout the great synclinal area to the south of the Gatsrand, the one end of which reaches the Vaal River.

While about 1500 feet thick in the southern part of the country the division swells out to not far from 5000 feet in the Zeerust district. It consists almost wholly of greenish-blue, fine-grained lavas of andesitic character, varying from compact stony types to highly amygdaloidal varieties, the vesicles being mainly filled with chalcedony and quartz.

In addition to lavas there are also igneous breccias, which may be developed at the very base, as in the town of Pretoria, or to the north of Marico Station. There are some thin intercalated sediments, generally thermally altered, particularly in the Zeerust district.

Petrologically the lavas are *andesitic* with feldspars replaced by zoisite and the laths of augite by pale green hornblende, making a felt-like aggregate in the manner termed pilotaxitic, thus agreeing in their texture with that of the Ongeluk rocks of Griqualand West. The thermal influence of the Bushveld norite is evinced in the recrystallisation of the silica of the amygdales, in the development of needles of hornblende in the latter, and in the devitrification of the groundmass.

The Daspoort Quartzites.—Typically represented by a single group of white, medium-grained quartzites a couple of hundred

feet thick, they take their name from the Daspoort Range in Pretoria.

In the southern part of the Rustenburg district the stage grows somewhat ferruginous towards its base. In the Dwarsberg it has split into two bands separated by shales and gives rise, therefore, to a double range, the lower one black and ferruginous; near Vliege Poort it carries a band of conglomerate. In the Potgietersrust area, though gritty, it is thin—only 80 feet in the Olifants River region—where, in spite of its refractory composition, it has been converted into a sericitic quartz schist north-west of the Mutse River. South of the latter it thickens, forms the Sagun Range, and splits into two bands, the Dwaal Heuvel Quartzite below and the Tunnel Quartzite above, which cross the railway between Waterval Boven and Waterval Onder. In the Potchefstroom district there is a single band 120 feet thick.

(C) *The Magaliesberg Group—The Magaliesberg Shales.*—This uppermost of the three argillaceous members, a full 2000 feet in thickness, has by reason of its proximity to the Bushveld Complex experienced considerable metamorphism; indeed, it is only in the Pretoria district that the shales are still found soft and bluish, for elsewhere they have largely been altered to hornfelses.

Along the upper valley of the Hex River the lower part of the shales become definitely *graphitic*, to form two well-marked carbonaceous horizons in the Zeerust district, the lower of which occasionally loses its graphitic character or is much altered. Such graphitic beds exist along the north-west of the basin and also in the valley of the Sand River north of Rooiberg. At Potgietersrust, not only are the sediments much hornfelsed but they have had developed near their base a *strongly calcareous phase*, in the shape of white and creamy banded crystalline dolomites with grains of yellow and green serpentine along with subordinate altered shales to the total thickness of fully 500 feet. This zone is traceable to the edge of the Springbok Flats. East of Chunies Poort the facies is of the normal argillaceous type, though altered to hornfels or even to banded "gneisses," while calcareous bands occur only sporadically.

The Machadodorp Tuffs.—These rather peculiar rocks follow on the Daspoort quartzites very closely, running from near Carolina to Machadodorp, some 25 miles, and again from the Steelpoort River

almost to the Olifants River, a distance of 33 miles; their maximum thickness is about 600 feet. The rock is bluish-green and very hard, with numerous fragments that stand out on the rusty weathered surfaces, consisting of various baked shales and quartzites, and greenish fine-grained igneous rocks. The matrix is dark-bluish, is volcanic-like in appearance, contains vesicles and exhibits flow-structure; contact metamorphism is evidently responsible for the devitrification in the groundmass. Very similar rocks have been noticed associated with the Ongeluk lavas.

The Magaliesberg Quartzites.—While forming the thickest of the three siliceous stages of the Pretoria Series, these quartzites must have been more imposing in the past, since the sequence is terminated by the Bushveld norite, while strips of intensely altered siliceous sediments isolated in the latter seemingly indicate the former existence of higher horizons. Indeed, such seems likely, for near the Premier Mine the belt is a number of miles wide; elsewhere from 1000 to 1500 feet of beds are represented.

By reason of its massive character this stage as a rule builds the highest of the three quartzite ranges, namely, the Magaliesberg (Plate VII, 1), which runs from Bronkhorstspruit in the east past Pretoria and Rustenburg to the Marico River, and forms the Tokane Mountain and the Steenkampsberg on the western side of the latter. East of Potchefstroom it crowns the solitary Losberg. In the Pretoria district it is a single body of white to flesh-coloured medium-grained (though generally recrystallised) sugary quartzites together with some flaggy siliceous beds; false-bedding and ripple-marking are common, while ferruginous bands are absent. To the west of Rustenburg it divides into three main beds parted by altered shales.

Just south of Potgietersrust not more than a couple of hundred feet of quartzite are present, while in the Olifants River valley there is but a single massive quartzite 100 feet thick. On the Steelpoort River to the south of Fort Burger it breaks up into four separate bands alternating with hornfelsed shales, but with some subsidiary strips still higher up in the norite. Thus augmented, the composite mass of strata extends through Lydenburg, no less than 2000 feet in thickness, the quartzites being white and fine-grained; the third of these composes the Steenkampsberg.

A fairly persistent zone of shale, marl, and siliceous limestone follows above the quartzite along the east and south of the

basin, converted by the overlying norite into hornfelses and calcite-wollastonite-garnet rocks.[1]

The Dullstroom Volcanics.—Commencing at Tonteldoos Post Office west of Lydenburg is a belt of lavas that extends along the western side of the Steenkampsberg to disappear beneath the Karroo beds south of the railway between Middelburg and Belfast. It attains a width of several miles, resting on the uppermost of the Magaliesberg quartzites and being followed by the Bushveld norite. The lavas are fine-grained and greenish, full of white vesicles filled with quartz, which stand out in knots on the weathered surface.

Acid labradorite and green hornblende can be made out in the thin section and the rocks are obviously lavas of andesitic character like those of the Ongeluk stage, only somewhat altered by thermal metamorphism; with them are associated some agglomerates. From their proximity to the village of Dullstroom the above name has been given to these lavas which, so far as can be judged, are not to be regarded as the effusive equivalent of the Bushveld diabase and norite. They form the highest zone of the Pretoria Series that we definitely know.

(D) *The Rooiberg Group—Relationships.*—Only in 1922 were the felsitic lavas, etc., of the Bushveld, into which the Red Granite is intrusive, found to be separated by an *unconformity* or *disconformity* from the so-called "Upper Waterberg" in which pebbles of felsite and red granite occur. The former had been placed by Humphrey[2] in a separate series called after the Rooiberg Tinfields, where they were typically developed and where the felsites overlay a thick group of quartzites, regarded as forming an integral part of that formation. There was always doubt whether those beds, unknown outside the Bushveld Basin, did not form the upward continuation of the Pretoria Series, but clear evidence was lacking.

Critical Sections.—(i) Along the only stretch where the Pretoria beds come into contact, namely on Zeekoegat, Leeuwfontein, and Kameelfontein north-east of Pretoria, the following apparently *conformable sequence* can be made out.[3] Between the main Magaliesberg quartzites and the Felsites ringing-in the Roodeplaat Centrocline[4]

[1] S. van Biljon, *T.G.S.S.A.*, 1937, xxxix, 45.

[2] W. A. Humphrey, *Ann. Rep. G.S. Tvl.*, 1908, 117.

[3] For the privilege of studying and discussing this section the writer is greatly indebted to Dr. L. G. Boardman.

[4] B. V. Lombaard, *T.G.S.S.A.*, 1930, xxxii, 151.

come about 1500 feet of "transitional beds" dipping at 45°-60° :—(*a*) thin felsitic lava and quartzite, (*b*) a group of highly altered shales, calcareous rocks, cherty tuffs and acid volcanic tuffs and breccias, (*c*) a coarse flesh-coloured feldspathic quartzite, (*d*) dark felsite and amygdaloid, (*e*) a thick and persistent group of andesitic lavas and breccias with intercalations of brownish quartzites, and (*f*) a pale quartzite with pebbles, overlain by the main Felsites. Syenitic sills are present in the belt, which is several miles long. The repetition of sediments and acid and intermediate volcanics is significant.

(ii) To the east, at Dullstroom, the Magaliesberg quartzites are for 40 miles followed regularly by up to 1000 feet of similar andesitic lavas (p. 146), separated, however, by norite from the Felsites which, suggestively, have no quartzites beneath them, though such appear more to the north, where the Dullstroom volcanics have in turn been cut out.

(iii) At Rooiberg [1] the so-called "Basal Quartzites," 2100 feet thick, pass through 350 feet of shaly quartzites, 400 feet of shales—with the Smelters Kop Quartzite at the top—900-1000 feet of andesitic lavas and tuffs with interbedded brownish feldspathic quartzites, a thin hard quartzite and then up to 1200 feet of typical felsites that cap the hilly ground. The resemblances to (i) are striking.

It is clear that the Basal Quartzites must represent not only the upper part, but an appreciable portion of the Magaliesberg quartzites, it being suggestive that, where they are present, as at Rooiberg, Stavoren, Zaaiplaats and Sekukuniland, the latter group is absent or incomplete in the neighbourhood. The term "ROOIBERG GROUP" will accordingly be taken to embrace merely the Felsites and the succeeding sediments preserved in the Middelburg Basin, leaving the andesitic rocks to form the uppermost stage of the Magaliesberg, as originally mapped. Because of long usage the term *Rooiberg Quartzites* can, however, be conveniently retained for that part now correlated with the top portion of the Magaliesberg Stage.

Through this reading, various difficulties important for the understanding of the Bushveld Complex and its emplacement become simplified.

Distribution.—The Lower Quartzites appear in a triangular area surrounded by intrusive granite in the Rooiberg Tinfields, consisting structurally of a "saddle" with a patch of the over-

[1] L. G. Boardman, *T.G.S.S.A.*, 1947, xlix, 103.

lying felsites on either side, building up the Elandsberg and the Rooiberg respectively. Because of their extremely tough and durable nature the felsites characteristically build high ground, its surface, strewn with loose blocks, rendering progress arduous; the slopes are but scantily timbered, while arable soil is distinctly rare.

To the north of Rooiberg the felsites compose the narrow range of the Hoekbergen, whence they strike in a rugged belt towards Warmbaths resting on the intrusive Red Granite and dipping beneath the Waterberg Sandstones. North of Nylstroom they cover a wider area, running north-eastwards towards Potgietersrust and then northwards past Zaaiplaats with similar relationships; this great escarpment, a couple of thousand feet in height, overlooks the valley of the Nyl (Fig. 27). On the northern side of the Waterberg basin rocks belonging to the series crop out again in the valley of the Palala River. Evenly overlying the norite from Zaaiplaats round to Sekukuniland is a zone of altered quartzites that to the south-west of Sekukuni Mountain is associated with a wide spread of felsites as well as the granophyric facies of the latter.

On the south-eastern side of the Springbok Flats at the Stavoren Tin Mines the formation makes a syncline composed chiefly of the lower sedimentary division, but embracing patches of the overlying volcanics, the whole resting upon a sheet of intrusive granophyre belonging to the Red Granite beneath, while farther to the south and also up the Elands Valley the felsites cover a considerable area, pierced at intervals by granite. This is merely the western end of a nearly continuous belt of these rocks that constitutes the northern edge of the Waterberg "basin" of the Middelburg district, following along the curve to the east and then turning westwards through Middelburg and traceable past Witbank, with the most southerly outcrops protruding through the Karroo beds 15 miles north of Bethal. In Middelburg not only do thin sedimentary intercalations appear on several horizons in the felsites, but the volcanic group is followed by a very considerable thickness of purple-black shales, by agglomerates, fine-grained red sandstones, and even conglomerates (Fig. 33), which display certain points of similarity with the strata of the succeeding Waterberg System. Broad fertile valleys follow the strike of the shale belt, bounded by stony ridges of felsite on one side and barren ledges of sandstone on the other.

The fact that the various stretches of this formation occupy a territory at least 200 miles by 150 miles, taken with the other evidence, suggests the full development of the Transvaal System over most of the Bushveld region prior to the emplacement of the Bushveld Norite.

Thickness.—In the Rooiberg mining area a value of over 2000 feet has been allotted to the lower group of quartzites, while the felsites certainly exceed several thousands of feet in thickness both here and in the Warmbaths and Pretoria districts, though, owing to the indistinctness of the dip, accurate estimation is often not possible. In the Middelburg district Mellor has reckoned the volcanic group to attain fully 8000 feet and the overlying sediments about 2000 feet; hence the series is of no small importance stratigraphically.

Subdivision and Lithology.—*Lower.* (*a*) At Stavoren, Wagner[1] has recorded greyish feldspathic quartzites at the base, passing up into red and brown quartzites, arkoses, grits, and even conglomerates with quartz pebbles, which at the top are interbedded with bluish-grey andesitic lavas and tuffs—presumably the equivalent of the Dullstroom volcanics.

(*b*) At Rooiberg[2] the quartzites—including a similar volcanic zone—are also grey and feldspathic and overlain regularly by the felsites. The intensely altered "meta-quartzites" intervening between the norite and granite between Zaaiplaats and Potgietersrust, and to the south-east of the latter place, must belong to this stage.

(*c*) On the Pienaars River, 15 miles from Pretoria, where they adjoin the Magaliesberg quartzites, there is apparently a downward passage into the latter.

The Felsites and Associated Granophyres.—It must be pointed out that the term "felsite" is merely a convenient "sack name," since it serves to include many other kinds of lavas ranging from rhyolites to andesites, in addition to inter-bedded breccias, agglomerates, tuffs, and sediments. Particularly is this the case towards both base and summit of the division; but the central portion is more uniform in its characters, so that one may have difficulty in making out the individual flows. The bulk of the felsites are brick-red to chocolate or purplish fine-grained rocks, hard, much and irregularly jointed, usually stony looking and without conspicuous minerals, at other times carrying small phenocrysts of flesh-coloured feldspar—mainly albite or

[1] P. A. Wagner, *Union S.A.G.S.*, 1921, Mem. 16; 1927, Expln. Sheet 17; *T.G.S.S.A.*, 1925, xxviii, 63.

[2] L. G. Boardman, *T.G.S.S.A.*, 1947, xlix, 81.

microperthite [1]—but with scanty ferro-magnesian minerals, chiefly hornblende. Vesicular structures are to be seen, but are by no means prevalent, though beautiful flow-structures can be observed on weathered surfaces as well as "pseudo-spherulites." Along the Selons River near Middelburg several of the individual lava flows are from 500 to 800 feet thick, their upper and lower portions frequently showing amygdaloidal or flow-structure, while towards their centres they become massive and porphyritic, and in the thickest sheets holocrystalline with moderately coarse and often granophyric texture (Plate X, 1).

The contacts between the Felsites and the intrusive Red Granite are sharp in some places; in others a transition seems to occur, occasionally through the medium of a red granophyre, which may be cut by dykes or veins of granite.

The intercalation of bands of flinty tuffs, shales, breccias, and sandstones on various horizons points to the deposition of sediments in the intervals between successive eruptions. An important zone of dark hard shales occurs in the midst of the felsites in the Waterberg district, notably in the Sterk River Valley.

Exactly how the felsites were erupted—whether from volcanic throats or from fissures—is unknown, but the trend of recent work is to regard them as having been poured out at the surface as a succession of flows, often to a great depth, so that the acid magma sometimes had to force its way out through the previously erupted matter and consequently solidified in places under considerable pressure and hence in the *form of granophyre*. This has been deduced from the fine sections at the southern end of Sekukuni Mountain and in Botha's Berg opposite. They also occur to the north of Pretoria in a belt running between the Norite and Red Granite from Pyramid Station to beyond the Crocodile River. These granophyric phases are uniform medium to coarse-grained, red, highly feldspathic rocks with hardly any dark minerals, but distinguished by a beautiful granophyric intergrowth of quartz and soda-rich orthoclase or albite-oligoclase. Their close relation to the felsites is brought out by Analyses Nos. 15 and 29. The felsites and breccias on Kruidfontein No. 47, west of Rooiberg, seemingly mark an eruptive centre.

Intrusive felsites are known on the Olifants River Tinfields and in the sheet surrounding the Premier Diamond Mine invading Magaliesberg quartzites—a reddish rock above, which differs slightly from the normal effusives (Analysis No. 28) and passes downwards in places into diabase.[2]

[1] B. V. Lombaard, *T.G.S.S.A.*, 1933, xxxv, 125.
[2] B. V. Lombaard, *T.G.S.S.A.*, 1933, xxxv, 125.

The Upper Sediments.—About Rhenoster Kop to the north of Balmoral the felsites are followed by several hundred feet of purplish-black shales and flagstones, and these by an equal thickness of coarse red volcanic agglomerate made up of fragments of felsitic lavas in a green matrix of finer fragments or of igneous material displaying flow structure. Round the eastern end of the Middelburg basin conglomerates, composed mainly of boulders and pebbles of igneous rocks derived from the volcanic group below, and sometimes of considerable thickness, frequently mark the base of the upper sediments, which are chiefly dark reddish-purple shales and bands of flagstones, sometimes beautifully ripple-marked; they are associated with thin beds of brick-red quartzitic sandstones. Such are well developed about the town of Middelburg, but to the north-east along the valley of the Selons River these softer beds pass laterally into soft massive purple-brown sandstones, which form the predominant facies farther to the north and north-west. They are overlain in turn *disconformably* by the basal conglomerates of the Waterberg System, in which boulders of the Red Granite are to be found.[1]

ECONOMICS.—Conspicuous are the bedded iron-ores at the top of the Dolomite and those in the Timeball Hill quartzites, while of great value are the asbestos deposits of the north-east, detailed in Chapter XX. Various metallic lodes appear to be connected with the Bushveld Complex, particularly those of tin. Gold occurs as a primary constituent in gabbro and was formerly worked at Waaikraal No. 206, Rustenburg district. Auriferous quartz veins traverse the strata on Koesterfontein and Blaauwbank to the west of Krugersdorp; the lode at the Willows Silver Mine near Hatherley contains chalcopyrite and tetrahedrite in a gangue of siderite; that at the Edendale Lead Mine on the road to the Premier Mine carries galena, blende, and their decomposition products, while the cobalt lodes are referred to elsewhere. The andalusite-bearing sands of the Marico district are being concentrated and the mineral exported.

B. The Transvaal System in the Northern Cape

Black Reef Series. Campbell Rand Series. Griquatown Series. Intrusions.

Distribution.—Rocks of the System make a compact block stretching from Prieska northwards to the Molopo, covering the

[1] F. C. Truter (*T.G.S.S.A.*, 1949, lii, p. lxvi) proposed the name Loskop System for the series of sediments lying above the Felsites and transgressing from them on to the Bushveld Granite north of Rooiberg, that are folded and unconformably covered by the basal beds of the Waterberg System around the Middelburg basin. Haughton (*T.G.S.S.A.*, 1950, liii, 205) suggested a correlation between the Loskop sediments and the Matsap System.

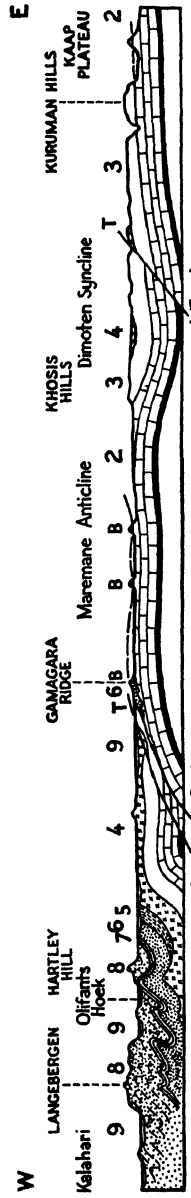


FIG. 24.—Section from the Kaap Plateau to the Langebergen, distance 73 miles. 1, Black Reef; 2, Campbell Rand Series; 3, Lower Griquatown Beds; 4, Ongeluk Volcanics; 5, Upper Griquatown Beds; 6, Lower Matsap Beds; 7, Middle Matsap Beds; 8, Upper Matsap Beds; 9, Kalahari Beds; B, Blink Klip Breccia; T, Thrust.

greater part of Griqualand West and Bechuanaland—territory that is flat on its eastern side, but rises in the west in the long curving chain of the Doornberg, Griquatown, and Kuruman hills; in the extreme north all except limited areas are deeply covered by superficial deposits.

The structure is very simple: resting for most of its course on the Ventersdorp lavas the Black Reef Series crops out along the eastern margin and passes below the gently inclined limestones and dolomites of the Campbell Rand Series of the Kaap Plateau, the latter in turn dipping beneath the Griquatown jaspers that build the mountainous section of the country. In the extreme west the System disappears under the younger Matsap System and together with the latter has been involved in the foldings that produced the Langeberg and Korannaberg ranges (Fig. 24). Only more ancient formations appear beyond, between Kheis and Upington.

1. The Black Reef Series

This group makes a few isolated outcrops to the north-east and north of Morokwen, but is not seen again till Garaphoane on the Mashowing River. Turning eastwards, it makes an important feature running from Keang Kop past Takoon and Geluk to Vryburg, displaying a series of pale false-bedded quartzites with some grits and conglomerates and thin shales to a thickness of from 150 to 200 feet. In the neighbourhood of Vryburg a zone of contemporaneous volcanics appears

between the dolomites and the Black Reef. The latter turns southwards down the valley of the Harts River, but the Karroo beds conceal its position except for certain inliers between Delport's Hope and Read's Drift on the Orange River. The group makes its next appearance along the western side of the Doornberg in a faulted and highly folded condition, while towards the north beneath the Ezelrand it, together with the overlying limestones, has been pushed forward repeatedly in slices by thrust faulting.

About Morokwen the quartzites probably do not exceed 30 feet, whereas in the Prieska district the thickness is more than 300 feet.

The pebbles in the conglomeratic bands consist of quartz, quartzite, agate, diabase, and banded ironstone. At its top the formation becomes shaly and carries some limestone, while in the section about Motiton some ferruginous beds occur in this position. Along the Vaal-Orange valley the series becomes less arenaceous; conglomerates are absent, while soft shales and flagstones play an important part, a character to be connected perhaps with the more shaly facies of the Campbell Rand beds in this section. West of the Doornberg the group grows quartzitic again and occasional pebbles can be found.

Base of Series.—Excepting in the stretch from Takoon northwards, the group rests on rocks belonging to the Ventersdorp System, generally the basic (Pniel) lavas. Near Motiton, where it passes on to the granite, the usually quartzitic base acquires a development of arkose.

Volcanic Zone.—Over an area extending from a little to the north-west of Vryburg down to Dry Harts siding at least, basic lavas with some breccias and tuffs to the thickness of 100 feet crop out at the very top of the Black Reef Series, in fact a little limestone occurs both below and interbedded with them; an earlier flow is found well down in the quartzites. The lavas are blue rocks, in places highly amygdaloidal, in places brecciated and sometimes containing fragments of quartzite, diabase, limestone, chert, etc., thus becoming agglomeratic. This recalls the section on the Olifants River in the Transvaal.

Economic.—The conglomeratic bands have been prospected at a number of points, but the gold values have invariably been low.

Water tends to make its way downwards into the Black Reef from the limestones above, consequently the relatively impervious base of the former is generally a water-plane along which springs issue, such as those at Takoon, or upon which supplies can often be tapped, for example in the town of Vryburg and at Spring Valley 12 miles to the south-east of Mafeking.

2. The Campbell Rand Series

Distribution. Relationships. Lithology. Water.

This name, originally given by Stow, has been used in the Cape partly because of priority and partly because the calcareous rocks are not infrequently limestones low in magnesia, to which the title " Dolomite " could not well be applied. Apart from this the outward differences between this formation and the Dolomite of the Transvaal are insignificant.

Distribution.—It builds the huge triangular flat of the Kaap Plateau with a maximum width of 80 miles, bounded by a rocky escarpment on the south-east and by ranges of Griquatown beds on the west, while towards the north the covering of Kalahari sand and calcareous tufa grows thicker, so that outcrops fail in the neighbourhood of the Mashowing River. After a wide gap another important area is met with to the north of Morokwen, wherein the belt is found trending east-north-east to the Mafeking border while, beyond, the formation with sills of diabase emerges to the west of Kanya dipping westwards.

Within this wide region, dotted with thorn trees and having not a few pans, outcrops are generally limited to occasional patches of rough-weathering limestone or ledges of chert projecting through the sand or tufa, wherefore determination of the dip of the formation cannot readily be made. Furthermore, the beds are lying at low angles, consequently the figure of a few thousand feet suggested for its thickness must be regarded as only approximate.

Beyond the Griquatown hills the limestones are brought to the surface again by the broad elongated dome of the Postmasburg-Maremane region (Fig. 24); but an insignificant isoclinal fold in the heart of the Korannaberg proves their sub-surface continuation far to the north-west. Folding has also brought up these strata along the western side of the Doornberg in a ragged belt stretching from the Ezelrand to Uitspanberg, with a string of inliers extending farther to the south-east, almost to Omdraais Vlei.

Relationships.—The transition from the Black Reef Series has already been referred to and recalls that seen in the Transvaal. At the very top chert is conspicuous, which may also carry thin

ferruginous or jaspery layers, showing that the change of conditions that caused such a striking difference in the nature of the sediment was not sudden and final; no defining conglomerate is, however, present as in the Transvaal.

In the face of the escarpment at Leijfontein just below Campbell *an intra-formational unconformity* was observed by Stow, which has since been found to have been produced by the arching up of the strata along a southeast-northwest axis during the deposition of the calcareous beds. At least 300 feet of rock were removed by denudation from its crest before the nearly flat-lying limestones were laid down upon the similar, gently inclined beds beneath. The occurrence, although local, is of importance in suggesting the relative shallowness of the ocean during that period.

Lithology.—In its general character, mode of weathering and in the presence of white, grey, and black chert as layers, lenses, and veins, the formation makes an exact parallel with the Dolomite of the Transvaal and the description of the latter (p. 132) applies almost *in toto*. One important difference, however, is in the development in the lower part of the series of dark bluish and greenish shales and flagstones from Vryburg down to Read's Drift at least, as bands ranging from a few feet up to 50 feet or more in thickness. Indeed, in the fine sections along the escarpment opposite Schmidt's Drift probably only about one-fourth consists of limestone in beds of varying thickness. This facies is very like that of the "Schwarzkalk" in certain parts of South-West Africa.

The calcareous rocks are mainly grey-, yellow- and brown-weathering magnesian limestones, but a low magnesia content is not uncommon, so that the rocks effervesce readily with dilute acid; some kinds are ferruginous. Below Prieska they seem to be more dolomitic. Thin beds of red chert passing into red and black-banded jaspers have been recorded from the midst of this formation near Omdraais Vlei and at Zeekoe Baart on the Orange River.

Water.—The limestones in the Kaap Plateau are traversed by solution-channels from some of which water issues in the form of strong springs. That for which Kuruman is famous comes from a fissure, which can be followed more than one hundred yards into the hillside and has a daily discharge of about four million gallons. Strong springs emerge on the Groot Vlakfontein

and Bothetheletsa Reserves, while a sinkhole at Geluk with standing water has a splendid yield. In some cases the water is thrown out by igneous dykes. Along many of the shallow depressions water is found at quite shallow depths in porous tufa. On many farms not so favourably situated the borehole yields have on the contrary been low.

3. The Griquatown Series

Historical. Distribution. Lower Griquatown. Lithology. Silicification. Blink Klip Breccia. Tillite. Ongeluk Volcanics. Lithology. Upper Griquatown. Origin. Economic. Intrusions.

Historical.—Noticed by the early travellers, these curious banded ferruginous jaspers were called the Griquatown Series by Stow in 1874 from the village of that name. In 1905 Rogers found them to be overlain by a volcanic group on which he bestowed the name of the Ongeluk Volcanic Series; but the discovery that the latter were in turn succeeded by more ironstones necessitated the adoption of the three-fold division of the *Lower* and *Upper Griquatown Beds* for the two ironstone groups, with the volcanics constituting the *Middle member* of the Series. The thickness of the first is 2500 feet, of the second over 3000 feet, and of the third 5000 feet.

Distribution.—This singular formation covers much of the western section of Griqualand West, the brown jaspers building up hills, which form a long arc running northwards from Prieska, named the Asbestos Hills in the south and the Kuruman Hills in the north; the highest point is Gakarusa, 6069 feet above sea-level. Interrupted by the Mashowing valley, the chain is continued northwards past Heuning Vlei and, after another gap, is taken up as a series of "islands" rising from a bush-covered sandy plain, the formation striking east-north-eastwards to the north of Morokwen as far as the Molopo and reappearing with typical development 10 miles to the south-west of Kanya.

Along this stretch of over 350 miles the strata are dipping westwards at gentle angles, in which direction they become folded into a series of arches and basins (Fig. 24). More to the west the rocks are buried by sand or pass beneath the Matsap beds of the Langeberg Range, while to the south of the Orange River the ironstones are involved in the close folding of the Doornberg.

(a) *The Lower Griquatown Beds—General.*—Having the widest development of the three subdivisions, the above description for the series as a whole will apply very largely to the distribution of this group.

The beds come into prominence through the abundance of ferruginous cherts or jaspery ironstones, banded in various colours, yellow, brown, or red tints being contributed by hydrated oxides of iron, black by magnetite, and blue or green by the soda-amphibole crocidolite. Among such singular types one is apt to overlook the existence of more normal kinds such as slates, quartzites, sandstones, and limestones, which play an important though at first sight perplexing part.

The Group is divisible into (i) a *Lower* or *Banded Ironstone Stage* in which well-bedded, white, brown, red, and black strata predominate with laminæ marked out by various iron-ores, and (ii) an *Upper* or *Jasper Stage* with an abundance of yellow-brown, poorly-bedded jaspers breaking with conchoidal fracture, while subordinate limestones may occur towards the top.

Owing to its hard and durable nature the formation everywhere gives rise to bare hills fringed with deposits of jasper rubble, while the sandy valleys are often filled in with similar debris. The presence of magnetite causes the rocks to be strongly magnetic and the compass is useless in their neighbourhood.

The limit with the Campbell Rand Series below may be sharp or made by a transitional zone, which around Prieska consists of white-weathering shales. The production of *brecciated rocks* along the contact, through solution, is discussed on p. 159. At the summit the " glacial band " forms a useful marker.

Lithology —On surface indications alone no more misleading formation can be found than the Griquatown beds and the corresponding facies in the Transvaal, since the deeper asbestos workings, reaching to 150-200 feet below the surface, furnish proof that these jaspery rocks are merely the oxidised and silicified equivalents of very different and varied sediments, often fairly soft and pale, grey, deep blue, olive, and black in tint. By following individual layers to their outcrop their passage into banded ironstones and jaspers—as end-products—can be demonstrated. In deeply eroded country patches within the jaspers may, however, be found that have become only partially silicified.[1]

[1] A. L. du Toit, *T.G.S.S.A.*, 1946, xlviii, 161.

The fresh parent-rocks include light greenish striped quartzites with magnetite layers; cream to grey cherts with carbonate layers, patches or crystals; deep blue, olive or black siltstones; graphitic shales; amphibole rocks of various kinds, and dolomitic or sideritic rocks. A feature is the rhythmic banding disclosed by alternations of these types. Chemical analyses show them to contain variable silica, high iron (as magnetite, ferrous silicates, siderite, or pyrite), fairly low alumina, lime and magnesia, but sometimes appreciable soda. Obviously most susceptible to weathering, they were much metamorphosed during the post-Matsap movements with the development of new minerals, particularly various kinds of ferriferous amphiboles, of which the cross-fibre seams of asbestos are important economically (p. 496). Limestones occur in thin layers on various horizons, but particularly below the tillite. An exceptionally developed band is that at Koegas 50 feet thick. They are greyish and crystalline and may contain magnesia and iron.

Little petrological work has been done on these fresher sediments. The cherts are composed of interlocking areas of quartz with rhombohedral or irregular patches of a colourless sideritic limestone, layers of magnetite or lines of magnetite granules, and needles of amphibole. The slaty types contain much chlorite and amphiboles such as crocidolite, cummingtonite, and grünerite. Conspicuous are the tough, vivid, or deep blue rocks composed essentially of minute fibres of crocidolite densely matted together without orderly arrangement and known as " mass-fibre " crocidolite.

It is within and from such materials that the seams of cross-fibre asbestos have been developed—in more than one generation. Dark needles of crocidolite and grünerite may in turn pierce the fibre, indication of a higher grade of metamorphism, which was apparently dynamic in its character.

Silicification.—The passage of these parent rocks into jasperoid material towards the outcrop has been attended by oxidation and hydration of the compounds of iron—including magnetite—loss of bases and accumulation of silica—apparently in the colloidal state with subsequent recrystallisation, precisely as in the *silcretes*.

The final product in each case stands revealed in thin sections as alternating bands of almost clear interlocking areas of quartz and dark layers with large grains of (primary) magnetite—often with crystal faces—and blotches and granules of deep red to yellow (secondary) hæmatite and limonite. Small scattered patches or rhombohedral areas filled with limonite, or bordered by limonite and filled in with

chert, represent replaced carbonates of dolomitic or sideritic composition. Analogous are cherts from the Black Reef Series at Schmidt's Drift with siderite crystals nearly half an inch across. Seams of cross-fibre crocidolite have frequently been pseudomorphed in silica in the surface zone, the colour of the product depending upon the amount of the iron retained and its state of oxidation, and so ranging in tint from yellow-brown through red and green to white. The brown pseudomorph is called " Tiger-eye " and is the " Crocidolite " of the jeweller. The degree of silicification has been the more intense the lower the rainfall, and is hence most marked in the Northern Cape. The action is presumably still in progress.

The Blinkklip and Siliceous Breccias. Called after the Blinkklip Kop close to Postmasburg by Stow in 1874, this remarkable breccia builds prominent cappings on the dolomite of that area, as in the Gamagararand, the Klipfontein hills, and even far to the south in the knob of Mount Carmel north of Daniels Kuil, referred to by Stow as Ramaje's Kop.

They consist of solid masses of fractured ironstones, highly shattered towards the base, but passing upwards through more coarsely broken material—with fragments of immense size—into undisturbed or slightly crumpled strata ; fine and coarse are jumbled together. The whole is strongly ferruginised and the fragments cemented by hæmatite and silica. In the extreme stage even the cherty matrix of the banded ironstone lumps has been replaced by iron oxides and a brecciated iron-ore produced glittering with scales of specularite.

Rogers [1] explained this striking facies as having been formed by the extensive slumping of the ironstones into solution-cavities in the supporting dolomite, in which view he was followed by Nel.[2] While evidence for some slumping is unquestioned, such would seem to have been largely of post-breccia age. The highly detailed mapping of the surrounding region, especially by Truter, Boardman and Visser,[3] is, however, all in favour of a *tectonic origin, produced during the post-Matsap thrusting.* Where the plane of dislocation has risen above the Dolomite-Griquatown contact, the Blinkklip facies has been developed, formed almost entirely of the shattered ironstones, but where it has descended into the Dolomite or risen into the Gamagara Series, the *Siliceous*

[1] A. W. Rogers, *Ann. Rep. G.C. for* 1905, 174 ; *for* 1906, 35.

[2] L. T. Nel, *Union S.A.G.S.*, 1929, " The Geology of the Postmasburg Manganese Deposits," 22.

[3] D. G. L. Visser, *T.G.S.S.A.*, 1945, 211, in which the subject is fully discussed.

Breccia has resulted, composed of broken chert, quartzite, or silicified shales. Sheet-like or lenticular bodies of one or other of these cataclastic types mark out such thrusts in various spots, as on Aucampsrust and around the Wolhaarkop, the Siliceous breccia underlying the Blinkklip variety. Strong hæmatitisation, manganisation, or silicification may have attended such thrusting. Indeed, over a wide region the Blinkklip breccia has been converted into workable hæmatite ores on a large scale, as in the Klipfontein hills (p. 527).

The Griquatown Tillite.—In 1905 Rogers [1] discovered immediately below the Volcanic group, or parted from it by a small thickness of strata, a hard, unbedded, splintery rock characterised by having pebbles and boulders distributed through it at random irrespective of size, many of them striated and faceted after the manner of the stones found in glacial till. Where fresh, as on Japiesrust, the matrix is blue or grey and calcareous in character and the rock is hard ; usually, however, it is red or brown, stained with iron oxides and softer, having lost its cement, while sometimes pebbles composed of limestone have also been dissolved out and the spaces thus formed partly filled with specularite. By weathering the inclusions are released, so that striated stones can easily be obtained (Plate VII, 2).

These consist mainly of dark grey cherts with some limestone and quartz and occasional quartzites, red jaspers, and grits, though igneous rocks are absent ; yet neither of the first two kinds is like those of the Campbell Rand and their source is unknown. Many of the chert inclusions, certain of which have been striated, are really flattened oval nodules. From two to six inches across is the commonest size the largest boulder noticed being about two feet long.

Good sections of the band are infrequent, but the tillite is usually under 100 feet thick and does not rest upon a striated floor, but passes downwards into bedded strata, in places quartzitic. The formation may be compound with the basal part coarser and more pebbly.[2] Near Koegas it is only 10 feet thick. From there it has been traced as far northwards as Madebing on the Mashowing River, the area including all the known outcrops being some 8000 square miles in extent. It must have had a very much wider distribution, however, and indeed the glacial horizon in the Daspoort group of the Pretoria Series can hardly be other than its representative in the Transvaal.

[1] *Ann. Rep. G.C. for* 1905, 162.
[2] *Union S.A.G.S.*, 1938, Expln. Sheet 173, 19.

Above the tillite there may be a thickness of up to 30 feet of shales and jaspers before the base of the Ongeluk lavas is reached, but near Upper Dikgatlon on the Kuruman River the volcanics follow directly, while the same is possibly the case at Folmink on the Orange River.

(b) *The Middle Griquatown or Ongeluk Volcanic Beds—Distribution.*—These volcanic rocks were observed by Stow at Ongeluk, a farm to the north-west of Griquatown, more than half a century ago, though identified by him with the much older lavas of the Vaal River valley. Resting in the main broad syncline of the Asbestos Mountains are two basins of the volcanics, that of Ongeluk and Witwater being 60 miles long by nearly 20 miles across, while that of Gathlose to the north is continued for a much greater distance, though on account of the deep red sand its course can only be made out from the exposures on the Kuruman River below Tsenin and those farther beyond on the Mashowing at Madebing. In the west of Hay lie the basins of Abrams Dam, Juanana, Koegas, and Lelyks Dam, the first of which is the largest, though much smothered by sand. To the south of the Orange River they are included in a narrow syncline in the Doornberg on the farms Uitspanberg and Glenallen and again on Keikams Poort farther to the south-east.

Within none of the above synclines have the Upper Griquatown beds been preserved, but to the north-west of Postmasburg that formation makes a belt 10 miles wide stretching northwards to the Gamagara River with the volcanics dipping regularly westwards beneath the Upper Division. Measurement of dips here is difficult, but a thickness of over 3600 feet of lavas has been computed elsewhere.

Lithology.[1]—The group consists almost wholly of volcanic rocks, principally andesitic lavas, the basal flows of which rest upon the glacial zone or upon some thin hard shales overlying the latter. These lavas are as a rule clearly distinguishable from those of the other volcanic groups in the Union, since they are fine-grained blue or greenish rocks with the peculiar structure known as hyalopilitic or pilotaxitic. Under the microscope are to be seen feathery microlites of augite or hornblende, small crystals of enstatite (or bastite pseudomorphs after that mineral), a younger clinopyroxene and laths of altered plagioclase set in a devitrified

[1] Descriptions of these rocks are to be found in *Ann. Rep. G.C. for* 1905, 179; *for* 1906, 44; *for* 1907, 64; *for* 1908, 88.

base. The flows are neither so frequently nor so highly amygdaloidal as those of the Ventersdorp System ; chalcedony, calcite, and chlorite fill the vesicles. Volcanic breccias and tuffs are also represented among the lavas, but closely related to them are rocks that are certainly intrusions.

It seems not unlikely that these effusions were *subaqueously erupted*, for along the Mashowing and Kuruman rivers some of the lava flows exhibit " pillow-like " structures, large blocks of compact rock up to 8 feet across rounded at edges and corners being separated from one another by darker laminated decomposed substances in which masses of vein-quartz fill up wedge-shaped spaces.

Peculiar to this group are lenticles of jaspers and cherts in the lavas, as on Dingle. They are intensely hard, though brittle, rocks mostly bright vermilion, but also greenish-black or grey. The black varieties owe their colour to magnetite, the green to epidote, and the red to very finely divided hydrated oxide of iron ; tiny yellow garnets are seen in places. Apparently these bands represent excessively fine-grained siliceous muds, possibly even chemical precipitates of gelatinous silica laid down on the top of one flow and baked by the succeeding one. Fragments of these conspicuously brilliant jaspers are spread quite abundantly over the surface in places. Identical rocks form small inclusions in the Dwyka conglomerate in the region to the south and south-west, and are also found as chips and pebbles in the Table Mountain Sandstones of the Western Cape.

(c) *The Upper Griquatown Beds.*[1]—This group is only known to the north-west of Postmasburg, making a long belt only a few miles wide apparently conformable with the Ongeluk volcanics and overlain unconformably by the Matsap rocks of the Langeberg. Both to north and south the belt passes beneath sand and indeed, over the strip itself, the rocks are much hidden. About 5000 feet of strata are represented, varying much in composition and including massive, brecciated and banded red, black, and brown jaspers and cherts, together with pale quartzites, dark slaty rocks, and blue limestones, with lavas and tuffs at the very top.[2]

Origin of the Griquatown Rocks.—That these singular types were the outcome of peculiar localised conditions is negatived by their wide

[1] Described *in Ann. Rep. G.C. for* 1906, 48.
[2] *T.G.S.S.A.*, 1945, xlvii, 207.

distribution in both the Cape and Transvaal. Since they follow dolomitic formations of presumed marine origin, it is highly probable that they were laid down in a shallow sea, to which the presence of occasional calcareous bands and of ripple-marks is not opposed. Clastic grains of heavy minerals are normally wanting. The magnetite, amphibole, etc., being of metamorphic origin, the parent sediments must have consisted of rhythmic layers of silica, carbonates, and iron-rich clays, partly in the colloidal state, the tendency being to regard them in the main as chemical gel-like precipitates.[1] It has been suggested that through base-exchange such calcium- and iron-clays could have yielded sodium-clay (suitable for generating crocidolite) and, through hydrolysis, silica and ferric hydrate (the source of the abundant chert and magnetite).[2] Alternatively the high soda-figure (6 per cent.), and occasionally potash content, could be ascribed to zeolites, analogous to the crystals forming today on the sea-floor along with the radiolarian oozes and ferruginous muds in the deeper parts of the ocean. The presence of the Glacial Zone is suggestive of low bottom-temperatures. A few algal-like impressions have been discovered in the jaspers.

Economic.—Outstanding in the Lower group are the seams of blue *Crocidolite Asbestos*, which are now being mined at many points scattered over a great stretch of country from south of Prieska to beyond Morokwen in the north (see p. 496).

The deposits of *Hæmatite*, including much high-grade ore, represented by the Blink Klip Breccia are truly enormous, though geographical considerations have hitherto prevented their exploitation.

The outcrops of the highly important *Manganese* deposits of the Gamagararand occupy an extensive area, the ore being of a high grade in places (p. 531).

Galena has been mined in flattish quartz reefs on the farm Balloch to the north of Niekerkshoop above the contact of a diabase sill in jaspers, 683 tons having been recovered. It also occurs in pockets in the dolomite at and to the north of Griquatown.[3] *Copper* occurs along a very basic dyke in the jaspers on the farm Juanana farther to the west. Attempts to exploit *Saltpetre* (potassium nitrate) not far from Prieska have been unsuccessful. It occurs as efflorescences on the walls of cliffs and rock-shelters amid the jasper hills, or as impregnations in the soil beneath, and is manifestly of organic origin, having only been preserved in those places where protection had been afforded from rain.[4]

[1] M. A. Peacock, *Amer. Miner.*, 1928, xiii, 241.
[2] A. L. du Toit, *T.G.S.S.A.*, 1946, xlviii, 161.
[3] *Union S.A.G.S.*, 1944, Mem. 39, 77.
[4] A. L. Hall, *Union S.A.G.S.*, 1919, Mem. 14.

Intrusions of post-Transvaal Age.—These are mainly of diabase penetrating the Lower Griquatown beds in the form of sills, as in the Groenwater Location or at Koegas, and also as dykes. Consisting of plagioclase, enstatite, and augite, all rather altered, some of them resemble the coarser varieties of the Ongeluk lavas, and perhaps mark the sources of those effusions. A mass of syenite pierces the strata on Prieska's Poort in the Doornberg.

C. South-West Africa and Namaqualand—The Stinkfontein, Kaigas, and Numees Series

1. Much resembling the near-by Nama beds—and indeed mistaken for them originally—is the Stinkfontein-Kaigas succession, thus named by Rogers,[1] that rests unconformably on Kheis beds and the grey Gneiss (Fig. 10).

(*a*) The lower or *Stinkfontein Series*[2] consists of a huge thickness of whitish to pinkish feldspathic, cross-bedded quartzites—locally ripple-marked—with conglomerate layers and a strong basal conglomerate, that dipping westwards at about 50° builds the north-south central massif of the Richtersveld. Northwards the group thins markedly, but southwards it passes a little east of Port Nolloth to about the mouth of the Buffels River. The sheared strata far down the coast at the mouth of the Sout River may perhaps be of this age. Interbedded thin lavas, agglomerates, and tuffs are numerous.

[*Editor's Note.*—Later opinion inclines to the view that the Stinkfontein Series may be of Witwatersrand, rather than of Transvaal, age.]

(*b*) The upper or *Kaigas Series* follows with some unconformity and consists of a variable sequence of greenish slates and phyllites, grey and yellow limestones and dolomites, thin sandstones, grits, and *tillites*. One such glacial horizon occurs at the base just south of the Kuboos Granite. Here clinohumite, forsterite, and chiastolite have been developed by contact metamorphism. This group dips westwards against a great strike-fault but reappears to the west of Annisfontein in a broad anticline with minor foldings—some overturned to the east—that stretches northwards across the Orange River to Obib, carrying numerous limestone bands, and ends on the west against the overlying "*Grootderm*" volcanics of doubtful age. The tillite reported by Knetsch[3] from Daberas on the Orange belongs, according to de Villiers, to this formation. Noteworthy is the general agreement with the Transvaal System.

[1] A. W. Rogers, *T.G.S.S.A.*, 1916, xviii, 72.
[2] P. G. Söhnge and J. de Villiers, *T.G.S.S.A.*, 1947, xlix, 263.
[3] G. Knetsch, *Geol. Rundsch.*, 1937, Bd. 28, 208.

Far in the south an isolated patch of somewhat schistose tillite rests on the gneiss at Moedverloor in Van Rhynsdorp and has provisionally been referred to this series by Lamont.

2. *The Numees Series.*[1]—This remarkable thick glacial formation, that rests unconformably on the older rocks up to the Kaigas Series, was so called by Rogers after the old copper mine in the Richtersveld, where it occupies a faulted strip, showing at least 600 feet of tillite, followed by 40-60 feet of limestone, 300-400 feet of dark arkose and up to 80 feet of limestone. The main belt makes a syncline 50 miles long and up to 5 miles wide cut in two by the Kuboos pluton, passing into South-West Africa at Sendelingsdrif, with a continuation northwestwards from Koivib to near Aurus, the strata displaying intricate drag-folding and shearing.

The material is largely a dark-grey, highly sheared tillite, with inclusions scattered irregularly through it ranging from small pebbles to boulders 8 feet across, on some of which, in spite of the shearing, glacial scratches can still be clearly distinguished (Fig. 25). It also includes more stratified material such as gravel or grit.[2] The inclusions are mainly gneiss along with granite, quartz porphyry, quartzite, schists, and limestones, noteworthy being boulders of an orange-red weathering limestone. Where invaded by the Kuboos granite, red biotite, cordierite, and magnetite have been developed.

At Lüderitz a highly sheared tillite, thought by Beetz to be the Numees, follows the shore for 9 miles, contiguous to gneiss. Although not assured, the evidence would indicate a pre-Nama age for the Numees tillite. Its thickness would suggest a possible equivalence with the Glacial Conglomerate of the Lower Kundelungu of Katanga.

3. *The "Folded Nama."*—It was believed by Kaiser and Beetz[3] that to the south-west of Aus the flat-lying Nama beds were continuous with the highly folded strata along the littoral between Lüderitz and Bogenfels that, under strong pressure directed from the Atlantic side, have become crumpled along axes trending south-south-east and have been pierced by the alkalic syenites, etc., of the Granitberg and its satellites and by intrusions of phonolite in the Klinghardt Mountains.

Their base is only clearly exposed in the west where the covering of sand is less. The basal quartzites, pebbly in places, rest unconformably on gneiss in the north and on chloritic and amphibolitic

[1] A. W. Rogers, *loc. cit.*; J. de Villiers, *T.G.S.S.A.*, 1946, xlviii, 135.

[2] Photographs of this rock and its inclusions are given by Rogers and de Villiers in the papers quoted.

[3] E. Kaiser and W. Beetz, *Die Diamantenwüste Südwestafrikas*, 1926, Bd. i, ch. vii; W. Beetz, *T.G.S.S.A.*, 1925, xxvii, 1; *Neu. Jahr. f. Min.* B-Bd, 1929, Abt. B, 59.

schists—the so-called " *Konkip Series* " [1]—in the south and east, and are followed by cream and occasionally grey dolomitic limestones, slates, and phyllites, and those apparently by highly contorted chloritic rocks resembling deformed volcanics. In the last of the synclines the limestones have been brought down along the shore and in them has

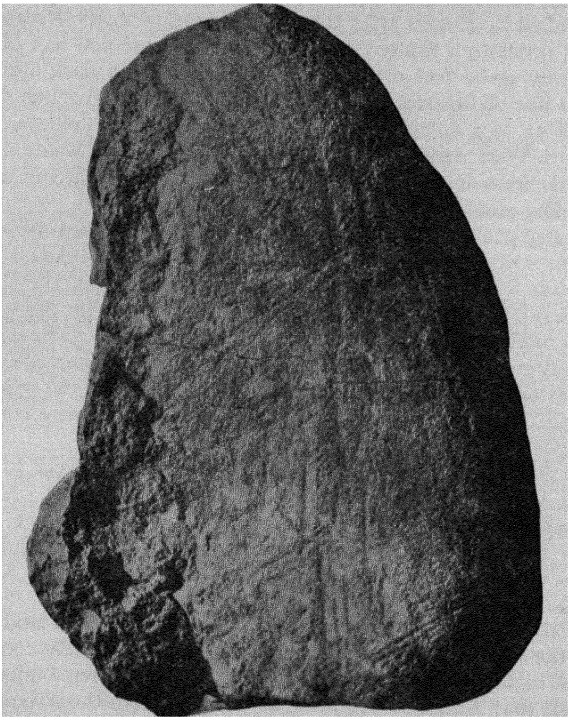


FIG. 25.—Striated boulder, 6 inches long, from the Numees Tillite, Namaqualand. Some of the matrix is to be seen on the left.

been eroded that picturesque natural arch known as the " Bogenfels." The writer's opinion is that this formation is definitely of *pre-Nama age* and comparable with the not far distant Stinkfontein-Kaigas, though possibly even with the Damara or Gariep Systems.

These important foldings run through Namaqualand and are presumedly continued in the similarly directed ones that traverse the Malmesbury beds from the Clanwilliam mountains southwards to

[1] W. Beetz, *T.G.S.S.A.*, 1923, xxv, 23; G. Knetsch, *Geol. Rundsch.*, 1937, Bd. 28,208.

False Bay, and are detectable within the Worcester area, where a more easterly strike becomes manifested.

D. South-western and Southern Cape

I. *The Malmesbury Beds.*[1]—These characterise the coastal districts of Piquetberg, Malmesbury, Stellenbosch, etc., always in the folded state, usually dipping at high angles and situated unconformably beneath the Cape System, sometimes as inliers brought up from below the latter, as, for example, in the narrow strip along the foot of the Langebergen between Tulbagh and Swellendam bounded on the south by the great Worcester Fault. There are also patches in Caledon, Bredasdorp, George, and in the Cango and Gamtoos valleys. Nowhere in the south, save in the Cango, has the base been seen, all normal contacts with the various bodies of granite being intrusive.

Over the flattish country southwards from Piquetberg extends an immense thickness of geosynclinal sediments, the full succession interfered with by strike-faulting, but arranged in two anticlinoria, the one coinciding with the upper part of the Berg valley, the other passing through Mooreesburg, in which the lowest horizons are seemingly represented (L. Rabie), all with a regular strike between north-west and north-north-west.

The strata are dominantly blue arenaceous clay-slates or fine-grained argillaceous quartzites that alternate with groups of phyllite, quartzite, ferruginous quartzite, dark feldspathic grit, and occasionally conglomerate, limestone, dolomite, chert, and basic lavas and tuff. Veins of white quartz are ubiquitous, fragments of which strew the surface or are embedded in the drab loamy soil.

Impure quartzites, forming the core of an anticline, build the chain east of Mooreesburg and are also seen at Breede River (Breërivier) and Goudini Stations approaching Worcester. Cleaved feldspathic grits and sheared arkoses, difficult to distinguish from igneous rocks, are common about Robertson. Coarse conglomerates occur at Honigberg on the Berg River. In addition to those in Van Rhynsdorp thick bands of *crystalline limestone* occur interbedded with dark slates at Piquetberg, Mooreesburg, Saron, Vogelvlei (Voëlvlei) south of Gouda on the Berg River near Hermon, on Norree and Klaas Voogds near Robertson, and on Bakovenshoogte between Ashton and Swellendam, as well as farther east, as mentioned below. All are low in magnesia and

[1] Considerable areas have been mapped in detail and horizons limited by members of the Geological Department of Stellenbosch University. (See *Ann. Univ. Stellenbosch*). See also F. C. Truter (*T.G.S.S.A.*, 1949, lii, p. li) who tentatively concluded that the Malmesbury Beds are the stratigraphic equivalent of the Gariep System of Namaqualand and therefore older than the Transvaal System.)

are in several cases used for making lime or cement, though there are *dolomites* as well. Basic lavas and tuffs are reported from the Berg Valley near Honigberg and at Blaauwberg shore opposite Cape Town, while basic sills occur occasionally.

Through dynamic action lustrous phyllites, marbles, and quartz-sericite schists were developed widely at this period. In contrast, however, under the much later Cape Folding, deformation was essentially by shearing (Rabie), well shown by the production of the chloritoid mineral ottrelite not only in the pre-Cape slates—as in the Elands Kloof inlier near Villiersdorp, to the north of Swellendam, and along the Langebergen—but even in the basal layers of the Table Mountain Sandstone, as at Waaikloof near Worcester.

II. *Contact Metamorphism.*—The various intrusive granitic bodies have in nearly every case produced considerable mineralogical changes in the surrounding strata, highly quartzitic beds having been least affected and purely slaty ones the most; hence at some distance from the junctions traces of metamorphism can be discerned only in certain of the more susceptible slaty layers.

Around the Paarl, Stellenbosch, and Somerset West granites the clay-slates become "spotted" at a distance of about 300 yards from the contacts; along the Cape Town mass, however, the zone of "spotting" is fully a mile and a quarter wide, the spots becoming larger and more numerous as the junction is approached, while at the same time very minute flakes of red-brown mica are abundantly developed. In thin sections the spots are clear aggregates of altered cordierite set in a finely crystalline quartzose groundmass containing biotite, and the dark rock can be termed a *hornfels*. Sharply bordered inclusions of similar material are abundant in the granite, but become more and more metamorphosed as the distance from the junction increases, ultimately forming dark-coloured patches shading off into the enveloping granite. They are rich in biotite, having acquired potash, and sometimes contain cordierite and garnet, but retain no trace of clastic structure.

Probably of similar origin are the sharply defined angular or rounded lumps in the granite-gneiss to the south and west of Darling, which are banded granulites of different kinds composed of quartz, plagioclase, sphene, and magnetite, with one or more of the following—biotite, augite, garnet, and pale brown hornblende. In several places to the east of this body and again in the George district, the slates become highly micaceous near the

contact and pass into typical mica schists—quartzose rocks that glisten owing to the innumerable flakes of pale mica arranged parallel to one another.

At Zwart River Bridge in George [1] a magnificent section is exposed in the road-cutting of andalusite schist, a rock composed of andalusite, mica, and quartz in which the crystals of the first-named mineral are often over 2 inches long. The schist occurs within five yards of a remarkably coarse muscovite-biotite granite dyke, which also contains tourmaline.

III. *The Cango and Gamtoos Areas.* (*a*) Pre-Cape rocks form a belt beneath the southern side of the Zwartebergen from near Amalienstein (Ladismith) to near Uniondale Road, fully 75 miles long and 10 miles wide in mid-section, tapering out in both east and west. This rough country with exceptionally fertile valleys is known as the Cango.[2] The beds are highly folded and sheared and generally inclined southwards at fairly high angles with the Table Mountain Sandstone apparently dipping in below them from the north, due to inversion, as well seen in the east (Fig. 58). On the south the belt is bounded by a thin strip of sandstone or else by downfaulted and crushed Cretaceous beds.

Lithology.—Represented by slates, limestones, grits, arkoses, and conglomerates, these beds have commonly been regarded as the eastward extension of the Malmesbury Series of the Worcester-Swellendam belt, though a younger age was suggested by the feldspars in the arkoses and pebbles of granite in the conglomerates, wherefore the term " Cango Beds " given them by Corstorphine in 1897.

The detailed work by McIntyre [3] along the Grobbelaar's River has disclosed the presence in the south of a basement of gneiss, granite, and schists, and towards the north of perhaps ancient dolomites (with chert) in anticlines. Grits, arkoses with very fresh feldspars, and conglomerates form the *unconformable base* of the Series followed by slates and phyllites with bands of limestone in the thickest of which are situated the famous Cango Caves. Discovered in 1780, these are among the finest stalactite caverns in the world. The walls and roof in those parts not disfigured by smoke are particularly beautiful owing to the number,

[1] E. H. L. Schwarz, *Rec. Alb. Mus.*, 1907, ii, 164.
[2] *Ann. Rep. G. C. for* 1898, 7, 68.
[3] R. C. McIntyre, *T.G.S.S.A.*, 1933, xxxv, 69.

form, and brilliance of the stalactites attached to them, while the floor is made partly of debris cemented with calcareous tufa and stalagmite. The main cavern is nearly half a mile long, but the passages have been explored for over two miles.

The limestones are grey or black and low in magnesia. Occasionally oölitic types are seen, which under the microscope show traces of organic remains, although no determinable shells have been found. Intimately associated with the limestones are bands of coarse quartz-feldspar grits—arkoses—sometimes with slaty, sometimes with calcareous, matrix and including fragments of slate, dolomite, granite, and quartzite, grading into dark feldspathic grits as, for instance, at Meirings Poort. Presumed higher strata are slates, quartzites, grits, and occasional thin limestones.

Of the pebbly zones the thickest is the well-known " Cango Conglomerate " finely sectioned in Schoemans Poort and presumably well up in the succession. It is packed with well-rounded boulders usually several inches across (though up to 2 feet in length), often much crushed, set in a schistose or gritty matrix. The boulder-beds are associated with small pebbled bands and sheared feldspathic grits. Certain bands are suggestive of a glacial origin. The inclusions consist of vein-quartz, quartzite, chert, hard slate, dolomite, granite, gneiss, and schist. Intrusions of much altered diabase are numerous, several of which are large, for instance one 8 miles long running east-west and up to a mile in width that crosses Coetzees and Potgieters Poorts.

(*b*) Similar strata reappear [1] in inverted position beneath the Table Mountain Sandstone in a strip extending from the Gamtoos across the Loerie River to Thornhill Station with downfaulted Cretaceous beds on the south, while their extension is seen in the Van Stadens and Maitland valleys and along the coast more to the east. Here again the lower beds consist of phyllites, with two thick horizons of limestones, followed by quartzites, feldspathic grits, and small pebbled conglomerates, usually sheared. Certain of the limestones are low in magnesia and are quarried for cement-making at Limebank. At the old Maitland Mine argentiferous galena and sulphides and carbonates of copper have long been known, occurring in irregular stringers, lumps, and impregnations in dolomitic limestone. The deposits are, however, unworkable.

[1] F. L. Amm, *T.G.S.S.A.*, 1935, xxxvii, 69 ; J. J. Frankel, *T.G.S.S.A.*, 1937, xxxix, 263 ; S. H. Haughton and D. J. L. Visser, *Union S.A.G.S.*, 1937, Expln. Sheet 151.

IV. *The French Hoek Beds.*[1]—The picturesque valley of French Hoek near Stellenbosch contains a group of slates, arkoses, grits, and conglomerates, folded in with the younger granite and quartz porphyry, certainly of later age than the latter, but older than the Table Mountain Sandstone and the Klipheuvel beds also. At the southern end of the Midden Berg a coarse basal conglomerate with worn boulders of quartzite, grits, slates, vein-quartz, quartz porphyry, and granite rests upon a mass of quartz porphyry; but elsewhere the strata in contact with the latter rock consist of cleaved grits and arkoses, which doubtless were derived from the disintegration of the plutonic basement.

Beneath the precipices due south of French Hoek these basal arkoses are followed by slates, succeeded by green sheared amygdaloid, while similar beds crop out at the head of the deep Wemmers Hoek Valley. Flanked by granite on the east and by Malmesbury slates on the west, a narrow strip containing highly sheared conglomerates and grits, intimately associated with presumed contemporaneous cherty felsites and felsitic tuffs,[2] extends along the western side of Simons Berg from Jonkershoek with expansion to the east of Klapmuts Hill. Similar beds have been mapped near Villiersdorp.

E. The Younger or Cape Granites

The age has not yet been established for either the plutonic masses of northern Namaqualand, or the numerous acid bodies, known as the " Younger or Cape Granites," that, from St. Helena Bay to beyond George, have pierced and metamorphosed the folded pre-Cape strata. The Nama beds are only slightly disturbed and strikingly free from intrusions other than occasional basic dykes or thin sheets. If the Klipheuvel beds prove their equivalent, they must be later than these Cape Granites.

That the majority of such bodies or " Plutons " have their long axes set parallel to the foldings, have commonly been intruded along cores of anticlinals, and often show a marginal banding, though hardly foliated in their interior, collectively suggest their introduction by the same forces that had crumpled those beds. The strata had, nevertheless, already experienced some low-grade metamorphism in certain areas, indicating that intrusion must have taken place towards the *end of the compressive period*, but the very oldest eruptives shared in such movements,

[1] Rogers and du Toit, *Geology of Cape Colony*, 1909, 47.
[2] S. H. Haughton, *Union S.A.G.S.*, 1933, Expln. Sheet 247, 19.

as, for example, at Brewels Kloof, Worcester.[1] This, and other evidence, would suggest a *pre-Nama dating.*

Several periods of intrusion can be made out exclusive of the minor dykes: (1) earliest gneissose phase, (2) older coarse porphyritic phase attended by shearing and some mineralisation along northwest-southeast lines, (3) aplite phase trending usually northeast-southwest.

Granites and granite-porphyries predominate, with some syenite in the Rooiberg of Namaqualand, and a little quartz diorite at Kuboos, Ysterfontein Point, and near Malmesbury. The porphyritic feldspar is usually microcline-perthite; the plagioclase ranges from albite to oligoclase. Biotite is dominant, while hornblende is sparsely distributed though more abundant at Stellenbosch (Analysis No. 16). Genetically connected are certain mineral deposits, for example cassiterite at Kuils River and elsewhere in the Stellenbosch and Cape districts, accompanied by arsenopyrite and wolframite; also copper at the Numees Mine in Namaqualand.

It is not yet clear whether the principal period of intrusion corresponded closely with that of the Bushveld Igneous Complex of the Transvaal.

Detailed Description. (1) *Namaqualand*

In the Richtersveld there are five bosses ranged on a northeast-southwest line of which the largest, the imposing block of Kuboos in the centre, is nearly 20 miles across. The rocks range from coarsely porphyritic types to granite-porphyries with dominant reddish perthite, a little biotite and scanty hornblende.[2] While of post-Numees age, their relations to the Nama beds remain uncertain though their characters suggest possible contemporaneity with those of the Southern Cape.

To the east stands the Rooiberg, made by rocks of unknown age ranging from granitic to syenitic types.

(2) *Southern Cape*

South of Piquetberg the various plutons are elongated in a northwest-southeast direction following the folding in the Malmesbury Series. The largest is that extending from St. Helena

[1] D. L. Scholtz, *T.G.S.S.A.*, 1947, xlix, p. 1.

[2] S. van Biljon, *T.G.S.S.A.*, 1940, xlii, 123; P. G. Söhnge and J. de Villiers, *ibid.*, 1947, xlix, 263.

Contact zone between the Malmesbury Slates and the Cape Peninsula Granite, on beach at Sea Point. The veining of the dark slates by the coarsely porphyritic granite is well displayed, also the streaking out of strips of altered slaty rocks (migmatites).

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Bay almost to Kalabas Kraal Station, a distance of 70 miles with a breadth of 17 miles, the chain of separate hills, with their bases hidden by sand, etc., rising to 1507 feet in the Kapokberg. This is a compound mass, the earlier intrusion being a coarse or medium-grained biotite or biotite-muscovite granite with so pronounced a foliation in places as to simulate a typical ortho-gneiss. Inclusions of the slates are not unusual and part of the body is contaminated. Tourmaline is often present, as near Darling. The later phase is a medium- to fine-grained granite transitional into granite-porphyry and into quartz porphyry at its margin. At Hoedjesbaai (Saldanha Bay) the chilled edge against the earlier granite is a green-grey quartz porphyry, which in thin section shows microcline-perthite feldspars and greatly corroded quartz crystals set in a glassy base, sometimes displaying flow-structure. Inclusions of the older granite can be found.

Not far distant is the lobed body 20 miles in length forming hills among which the town of Malmesbury is situated, with the rugged Paardeberg rising to 2488 feet due to an extensive capping of the finer-grained " roof facies." The Paarl boss is 9 miles long, symmetrical and rising into fine bare domes in the Paarlberg (2392 feet). On its summit and along its eastern and north-western flanks the coarse granite passes into a medium-grained biotite variety, while quartz porphyry offshoots have invaded the slates on the west and south.

Passing beneath the Table Mountain Sandstone at Wellington is another elongated mass with inlying portions visible in Du Toits Kloof and the Wemmers Hoek Valley, while a large body, supporting the Simons Berg, extends under the sandstone into the French Hoek Valley and Jonkers Hoek, and is probably continuous with the granite that emerges from beneath Sneeuwkop and stretches to Sir Lowry's Pass, a distance of 24 miles. Gneissose types are not uncommon. Quartz porphyry predominates in the French Hoek Valley, one variety being a handsome rock with large twinned salmon-pink crystals of microcline-perthite set in a bluish stony groundmass.

The Kuils River-Helderberg pluton is parted from the Stellenbosch body by only a few miles of slates and is coarse-grained and gneissose in places, *e.g.* on its western border. On the rise overlooking Kuils River it is traversed by greisen and quartz veins with cassiterite, wolframite, and tourmaline. On the axis of this body, but more to the south-east, there projects the

Schaapenberg stock,[1] 2 miles across, consisting of medium-grained porphyritic biotite granite cut by a younger fine-grained variety passing into quartz porphyry and carrying andalusite near its contact with the Malmesbury beds. Subsequently the mass was traversed by greisen veins containing tourmaline.

The Cape Town granite extends the full length of the Peninsula and is almost throughout a grey porphyritic biotite granite with twinned crystals of white microcline-perthite up to 3 inches across, ubiquitous dark rectangular pseudomorphs in pinite after cordierite and a little muscovite (Analysis No. 17). Small inclusions rich in biotite, tourmaline, and cordierite and occasionally garnet are common, while the rock is cut by veins of aplite, greisen, or quartz. The contacts with the altered slates at Sea Point and in the Platteklip ravine under Table Mountain have long been famous, having been first mentioned by Capt. Basil Hall in 1813 and described in detail by Cohen in 1874.[2] On the beach at Sea Point the junction is a most instructive one, the slates being penetrated by such a network of granite veins that an intimate mixture of sedimentary and igneous matter forming a belt several hundreds of feet wide lies between the spotted slates and the main granite body. The coarsely porphyritic nature of the granite in contact with the slates and in the narrow veins that penetrate them is extraordinary. In many of these strips the bedding planes are recognisable and their boundaries are sharp; in others there is a gradual transition, and grey streaky migmatite rocks have been produced in which well-formed microcline crystals an inch or two in length often form "eyes" (Plate VIII). It has been suggested that in the migmatite zone plastic flow was followed by feldspathisation and the development of porphyroblasts of microcline.

Of the minor plutons to the east, that at Robertson is about 5 miles across and composed of moderately coarse, unfoliated granite enclosed in a finer-grained shell, a character repeated in the partly exposed body at Swellendam.[3] The George mass, 30 miles from west to east and from 4 to 8 miles across, with two sill-like offshoots on its south-eastern margin, and the Touws River or Woodville one to the east, about 10 miles by 2 miles, show rather similar characters. Along the coastal section south and east of Pacaltsdorp belts of pale gneisses are veined by granite and aplite often carrying tourmaline. The slates surrounding these masses

[1] A. R. E. Walker, *T.R.S.S.A.*, 1917, vi, 193.

[2] E. Cohen, *Neu. Jahr. f. Min.*, 1874, 460; E. H. L. Schwarz, *T.G.S.S.A.*, 1913, xvi, 33; F. Walker and M. Mathias, *Q.J.G.S.*, 1946, cii, 499.

[3] D. L. Scholtz, *T.G.S.S.A.*, 1947, xlix, Pl. II.

are heavily injected with granitic dykes, as along the Kat River. While like those of the Western Province, though slightly more acid, these granites have suffered much crushing and shearing with production of secondary muscovite, clinozoisite, etc., for which the strong Cape Folding may have been responsible.[1] The easternmost body is one in Baviaans Kloof.

F. Southern Rhodesia—The Lomagundi System [2]

Distribution.—These beds must be widely represented in both Southern and Northern Rhodesia for they appear in the south from beneath Karroo strata near the Umniati River in a belt fully 70 miles wide, stretch for 100 miles through the Lomagundi district towards the Zambezi, and reappear beyond that river in the Kafue Valley and at Lusaka.[3] Their eastern boundary runs in an even curve from the Umniati past Sinoia to the middle reaches of the Angwa River, and, in agreement therewith, the strike curves round from north-east in the south to north-west in the north. They dip at moderate to high angles, have experienced considerable compression with development of a strong cleavage, and have towards the east been thrown into complex recumbent folds with faulting and thrusting from the west. The harder bands produce strike-ranges, while a synclinal spur forms the Hunyani Range. The western limit is more irregular because of a northeast-southwest cross-folding. The thickness of the Lower Division is about 6000 feet in the south-west, but that of the Upper is uncertain owing to the isoclinal folding.

Stratigraphy.—The base is everywhere *unconformable* (Fig. 26), resting on the Deweras Series in the Umfuli Valley, on the Eldorado Series and Greenstones near Sinoia, and generally on the Old Granite elsewhere. The sequences recorded in the east and south by Molyneux and Macgregor, and in the south-west by Phaup and Dobell, show divergences which may be largely due to changes in facies, particularly the dolomite members.

A. The Lower Division, Hunyani Range or Arenaceous Series consists in the south of :—(1) Basal (and impersistent) conglomerates, arkoses, and dolomite. In this dolomite are

[1] D. L. Scholtz, *ibid.*, 1947, p. xxxviii.

[2] A. J. C. Molyneux, *S. Rhod. G.S.*, Bull. 6, 1919; Bull. 9, 1923; Short Reports 8, 1920, and 13, 1922. A. E. Phaup and F. O. S. Dobell, *S. Rhod. G.S.*, Bull. 34, 1938; and also Short Reports 10, 1920, and 25, 1931.

[3] R. Murray-Hughes, *Q.J.G.S.*, 1929, lxxxv, 109.

situated the well-known Sinoia Caves. (2) Lower Quartzites, 500 to 1000 feet thick. (3) " Pocked " Quartzite, 500 to 600 feet thick, with peculiar pittings. (4) Upper Quartzites, about 3500 feet thick, and more variable. (Nos. 2, 3 and 4 are all pale and strongly false-bedded, while some are round-grained and dune-bedded.) (5) Main Dolomite up to 1350 feet thick, fine-grained, pink, cream or grey with quartzitic bands and much silicified in parts. More to the north it is overlain by a thick quartzite.

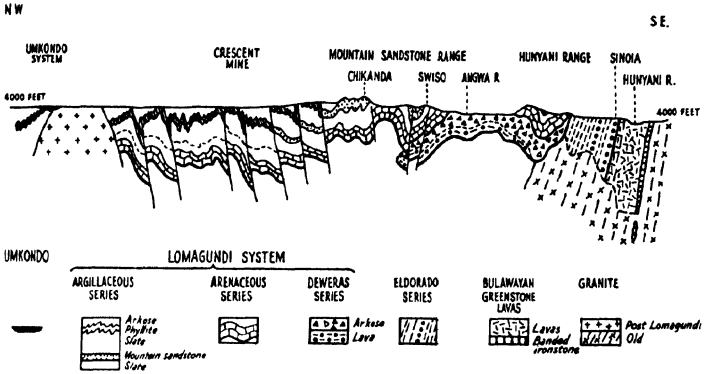


FIG. 26.—Section 50 miles long through the Lomagundi System, vertical scale twice horizontal (Geological Survey, S. Rhodesia).

B. THE UPPER DIVISION OR ARGILLACEOUS SERIES embraces (6) Striped Slates, essentially grey, black, and purple, (7) Mountain Sandstone, a thick zone of quartzite and dolomite, which is peculiar in that the quartzitic portions appear to have arisen largely by intense silicification of the carbonate-rock, and (8) Piriwiri Beds, a thick folded group of graphitic slates, phyllites, and thin quartzites with greywackés and slates at the top.

Metamorphism.—Around Sinoia and southwards this has generally been low, increasing to the west, where amphibole may appear, but particularly to the north, where by means of such types as cyanite-bearing arkoses there is a passage into the garnetiferous mica schists and paragneisses of the Miami Mica Fields and Zambezi Escarpment. The numerous pegmatites and pegmatitic quartz veins scattered over a vast area, coupled with granitic bosses near Miami, suggest an intrusive granite of wide distribution underfoot, corresponding doubtless with the younger

" Hook Granite " of Northern Rhodesia. Much of the gneisses striking north-westwards towards the Kafue Bridge consists of granitised sediments indistinguishable from types representative of the Basement Complex.

Correlation.—The magnitude of the Lomagundi System, its unconformable relations to the older groups, the general succession, the prominence of dolomite in the lower portion, the presence of slates and particularly of graphitic varieties in the upper, and of occasional andesitic lavas, suggest comparison with the Transvaal System rather than any other. The older, dominantly volcanic Deweras Series can thereupon be correlated with the Ventersdorp System (p. 116). On the contrary, the extraordinary transfusion of the Lomagundi into material indistinguishable from basement gneiss strongly suggests a far greater age. Macgregor, moreover, points out [1] that the Great Dyke must have been intruded after not only the granitisation but the erosion of the fold-ranges into which those beds must have been thrown, and that on such a basis the time-interval would seem far too short.

Economic.—To the number of mineral occurrences in the rocks of this system is due the name "Lomagundi Copper Belt." Most of them were discovered and worked by the " ancients," though none appears to be workable at present. The veins are generally of quartz with chalybite along zones of fracturing and brecciation and in addition sometimes carry gold, particularly in the ferruginous gossans, but the presence of copper renders extraction difficult. Mica is mined from pegmatites around Miami.

[1] *S. Rhod. G.S.*, Bull. 38, 1947.

CHAPTER VIII

THE BUSHVELD IGNEOUS COMPLEX AND THE ASSOCIATED ROCKS

Introduction. Bushveld Lopolith. Structure. History. Norite. Red Granite. Petrography. Differentiation. Metamorphism. Transfusion Hypothesis. Great Dyke, Rhodesia. Vredefort Area. Economic.

The following account includes not only the Complex itself, but also certain igneous masses of presumed similar age in the district of Heidelberg, about Parys, in Bechuanaland (perhaps) and in Southern Rhodesia. The alkaline and associated rocks of the Bushveld region will, however, be described in Chapter XI, since they were erupted at a much later date.

Introduction.—The Bushveld Igneous Complex—or rather what remains thereof—occupies an elongated area in the centre of the Transvaal fully 300 miles long from east to west. Large sections are, however, concealed by later formations, while there is no clear indication of its original dimensions.

The different groups of the Transvaal System dip rather regularly inwards towards the heart of the basin, in which direction they are overlain by a great quantity of norite and red granite, together with some granophyre, abundant diabase, and certain ultra-basic rocks. This intrusive igneous assemblage forms one of the most remarkable of geological occurrences in the world, standing unrivalled as a study in igneous injection, magmatic differentiation and thermal metamorphism.

It was introduced within the upper part of the Pretoria Series mostly, probably while the latter was still horizontal, and marks apparently a climax in geosynclinal sedimentation. By subsequent depression of the interior the Pretoria quartzites and shales were tilted towards the centre and so gave rise to a striking series of regular dip-slopes ringing-in the basin; these dip beneath the Norite and that in turn below the slightly younger Red Granite. The outstanding feature is the successive introduction, apparently from the same reservoir, of *two contrasted magmas*, one basic, the other acid, throughout this vast region.

Up to 1946 the purely " igneous " nature of these rocks had never been questioned, but S. van Biljon has since presented evidence to support the startling view that much of these holocrystalline rocks—ranging from ultra-basic to ultra-acid types—represents largely, if not entirely, *transfusions* of the enclosing or replaced sediments, with " mineralisers " playing a vital rôle (see p. 193). Under that revolutionary concept such current terms as " intrusive," " magma," etc., lose much of their significance, an aspect which will have to be kept in mind when reading this account.

Outside the basin proper are certain intrusive bodies which, although of widely different habit, seem connected with this period of enormous magmatic activity: for example, the " Great Dyke " of Southern Rhodesia.

The Bushveld " Lopolith " [1]:—While its structure—being as a whole that of a basin with the sediments and sheet-like igneous masses dipping towards its centre—corresponds in some ways to that known as a " laccolite " or " laccolith " (Greek *laccos*, a reservoir), it agrees better with that termed a " lopolith " (Greek, *lopos*, a basin) by Grout in describing a mass with flattish top and basin-shaped floor, a type represented by the Sudbury " basin " in Canada. The rather similar occurrence in the Transvaal can in consequence be referred to as the " BUSHVELD LOPOLITH." There are, however, reasons for deducing that the basin-form was, in part at least, derived at a later (post-Norite) stage from a previous laccolithic shape. Following denudation, the Complex and its framework were buried beneath Waterberg sediments—to which they contributed *débris*—and the symmetry of the basin became modified by post-Waterberg earth movements, mainly along its northern and southern margins.

Structure.—Younger beds cover a good deal of the centre, north-west and south-east, but the structure is quite clear, making allowances for appreciable compression along such belts and for some post-Karroo warping and faulting. As will be seen from Fig. 27, it forms a pear-shaped area, its western end just passing into Bechuanaland. As Hall has stressed, the major axis trends

[1] The literature has been summarised and the problem discussed by R. A. Daly and G. A. F. Molengraaff, *Journ. Geol.*, 1924, xxxii, 1; R. A. Daly, *Bull. Geol. Soc. Amer.*, 1928, xxxix, 703, but most fully by A. L. Hall, *Union S.A.G.S.*, 1932, Mem. 28, supplemented by E. Reuning, *XV Inter. Geol. Congr.*, 1930, ii, 37, and B. V. Lombaard, *T.G.S.S.A.*, 1934, xxxvii, 5.

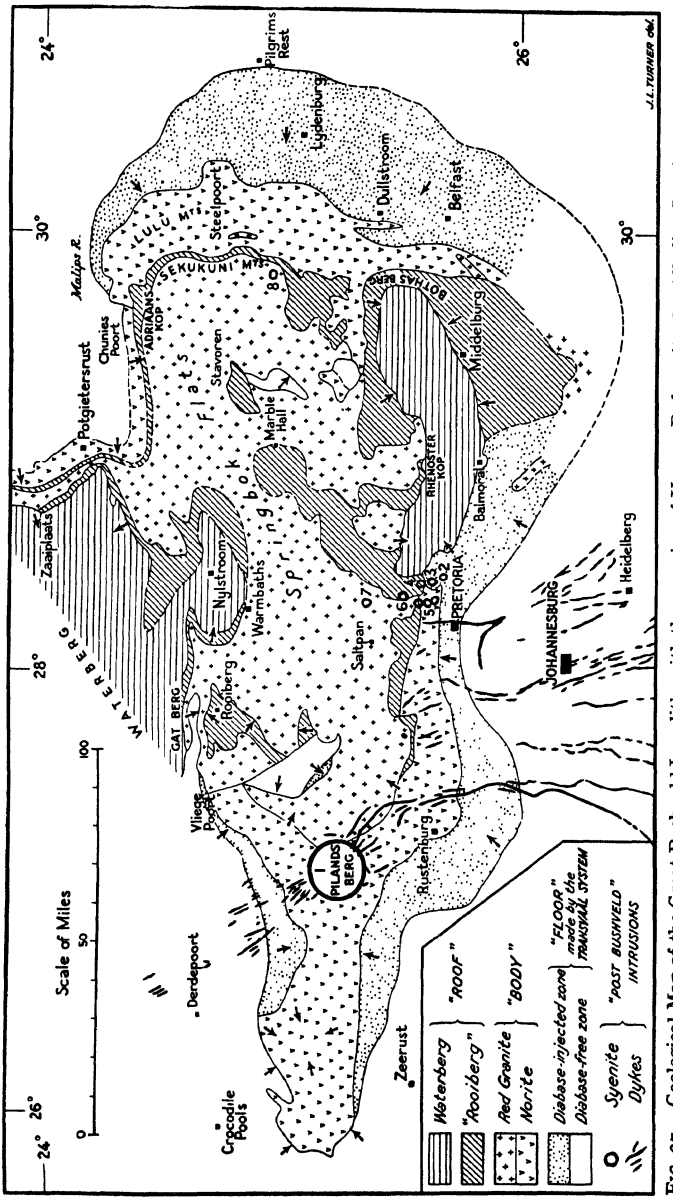
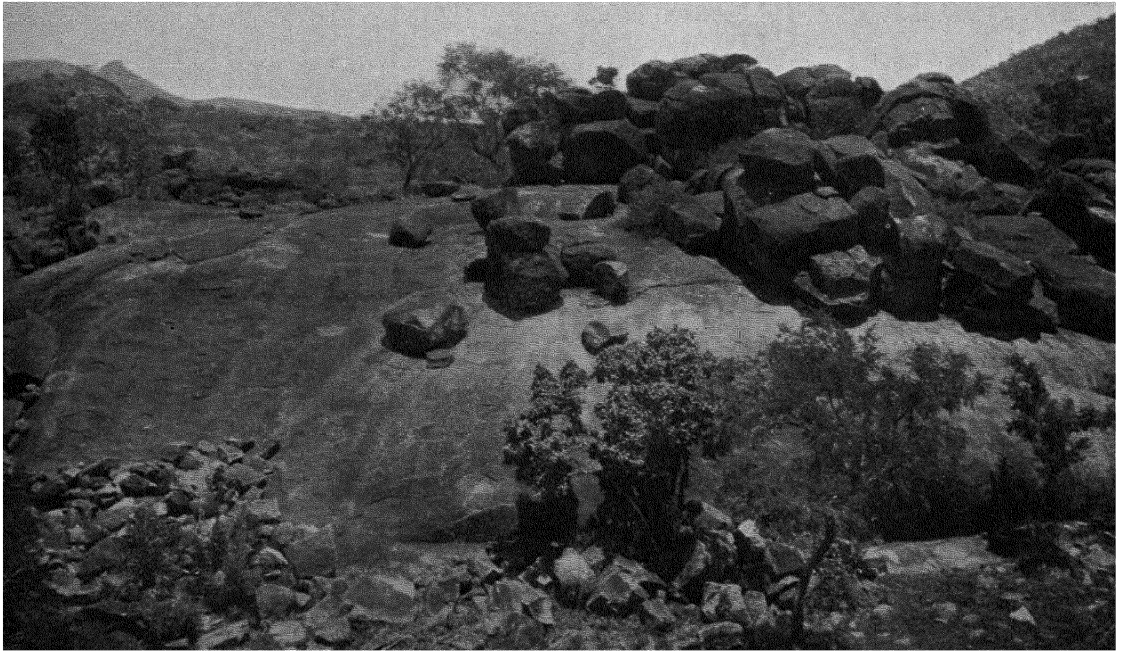


FIG. 27.—Geological Map of the Great Bushveld Lopolith, with the covering of Karroo Beds omitted. Alkaline Syenites:—1, Pilandsberg or Pilansberg; 2, Franspoort; 3, Leeuwfontein; 4, Walmansthal; 5, Leeuwkraal; 6, Spitzkop; 7, Roodeplaat-Derdepoort Line; 8, Zeekoegat.



Weathering of Bushveld Norite, north-east of Rustenburg.

PLATE IX

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(*c*) Sill Phase of Diabase sheets injected into the foundation, though possibly overlapping (*d*) in time.[1]

(*d*) Earlier Main Plutonic Phase with introduction of basic magma—crystallising as the Norite—along a horizon well up in the Pretoria Series and mostly below the Rooiberg Felsites.

(*e*) Later Main Plutonic Phase of the Red Granite, cutting across and spreading out above the Norite, largely between the latter and its covering.

(*f*) Alkalic Phase—post-Waterberg and therefore much later.

The "Norite."—Always dipping towards the centre of the basin, this forms a belt from 5 to 12 miles wide, curving through the Pilansberg and sending an extension westwards to the Bechuanaland border, interrupted at two points, in the Waterberg and Middelburg districts, where it is cut out by the Red Granite though probably continuous beneath it. In the east the belt is a full 20 miles broad, mainly owing to the lower dip, but to both south and north it gets narrower and at Potgietersrust crosses the entire Transvaal System and shows out below the Black Reef. The covering beneath which it was introduced is represented in the east by the zone of quartzites bounding the Steelpoort Valley and by the felsites extending along the flanks of Bothasberg southwards to the head of the Olifants River; elsewhere the norite is overlain by the Red Granite (Figs. 22, 23, and 29).

Resting usually on some part of the Magaliesberg quartzites, it lies upon the higher Dullstroom lavas in the east, where it has given off an extensive sheet into the floor well beneath the main norite body. It also carries as inclusions strips of Pretoria beds, some of them miles in length. Its full thickness has been estimated at about 30,000 feet.

The homogeneous norite, as in Zone 4, produces ridges and tors (Plate IX) of brown-weathering jointed rock with a tendency to run in lines parallel to the strike of the adjoining sediments.

Throughout the region one finds a conspicuous "*pseudo-stratification*" or "*rifting*" that agrees perfectly with the dip of the strata of the floor or roof, wherever the latter is preserved. In the homogeneous norite this is due to the orientation of the minerals, but it is developed in high degree by the presence of

[1] H. J. Nel, *T.G.S.S.A.*, 1941 xliii, 67.

fairly regular bands or zones of less or more basic composition, or of layers of magnetite-rich or chromite-rich rock intercalated in the norite, the persistence of which is often amazing, as in the Lulu Mountains of Sekukuniland. Indeed, a series of ledges and dip-slopes may have been produced running for miles and conforming in dip and strike to those of the strata making the floor. Such a character is finely presented in the Lydenburg district.

It has actually been found possible to subdivide this immense cake of crystalline rock into the following " ZONES," from above downwards, that may each occupy widths on the ground of up to several miles [1] :—

(5) The *Upper Zone*, up to 9000 feet thick, marked out by fairly uniform types ranging from gabbro to granodiorite and becoming somewhat pinkish and less basic towards the " roof."

(4) The *Main Zone*, about 15,000 feet thick, composed of rather uniform norite and gabbro, that builds ranges and isolated hills, such as the Pyramids, Pretoria, with its upward limit defined by iron-ore bands, some over 10 feet thick, as at the Magnet Heights west of Lydenburg.

(3) The *Critical Zone*—very well studied—2500-3000 feet thick, characterised by a pseudo-stratified and contrasted succession of highly differentiated types such as pyroxenite, anorthosite, chromitite, peridotite, with the Lowest Chromitite horizon at the bottom and the " Merensky Reef " (diallage norite) at the top, and thus including the platiniferous deposits. Though persistent, and present in the extreme west also, it is not typically developed at Potgietersrust.

(2) The *Basal Zone*, less continuous, composed of norite, gabbro, and thin bands of pyroxenite, giving rise to linear features, as seen near Malips Drift.

(1) The *Chill Zone*, thin and variable but prominent in the north-east, with its narrow development of fine-grained norite, diabase-norite, and contaminated rocks along or just above the " floor " near Potgietersrust.

The *Pyroxenites* and *Peridotites* peculiarly occur on horizons not at the very base, but well within the mass of the Norite. They

[1] As revised by B. V. Lombaard, *T.G.S.S.A.*, 1935, xxxvii, 23.

are furthermore present in proper position in the Marico basin along with layers of chromitite (Boardman). The *Iron Ores*, moreover, have been concentrated mainly on two horizons, the lower rich in chromium, the upper in titanium.

The *Diabase* sheets—*Bushveld Diabase*—range from a few feet to over a thousand feet thick, following the bedding-planes rather closely and rarely crossing the latter except very obliquely. Outside the Basin they have a wide development, to far beyond Parys and Klerksdorp.

A few thin ones appear low down in the Pretoria Series or even in the Dolomite, but they become on an average more numerous and thicker higher up, the highest passing by degrees from the normal greenish diabase into the paler and more coarsely crystalline grey norite. While such is the general relationship, the Norite occasionally rests directly on the sedimentary floor, while just beyond the Pilansberg it has given rise to an extensive sheet in the basement strata, well below the bottom of the main norite body.

The Norite directly underlies and is intrusive into the Felsite-granophyre complex in the upper part of the Steelpoort Valley where, as for example in the Tautes Hoogte, peculiar darkish monzonites are stated to have been developed by reaction.

The Red or Bushveld Granite.—Bursting its way through the floor with its diabase sills and the already consolidated norite, and that in *more than one phase*, the acid magma spread out within the Lopolith as a vast cake between the norite and its roof, or along a horizon just within the covering, as in Sekukuniland and near Potgietersrust, where a body of "Rooiberg" quartzites intervenes between the Norite and the Granite. This cake of Granite occupies the *central part of the Basin*, from the northern Waterberg to the Middelburg district and from the Pilansberg to the escarpment of Sekukuni Mountain, an area over 200 miles across. Conforming fairly well with the general dip in the basin, its thickness must be great, estimated at 8000 feet in the Zaaiplaats area (Fig. 29). The fact that the Red Granite appears on the Palala River, that it is irregularly transgressive in the area traversed by the Crocodile River, and that subsidiary intrusions penetrate the rocks outside the basin between the Marico River and Crocodile Pools, strongly suggests that the acid magma must have forced its way up from the subterranean "cauldron" on this (northern) side of the lopolith. It furthermore envelops huge masses floated up from the ruptured

floor, such as the Crocodile and Olifants River blocks. "Stratification" within the sheet could hardly be expected, though at Stavoren and elsewhere a zone of granophyre and one of granite are to be found between the main body and the quartzite and felsite roof. The super-position of the Granite on the Norite is finely seen in the plateau of the Sekukuni Mountain, more particularly at the southern end, where several outliers of granite appear capping a base of norite, *e.g.* Spitzkop. It is wanting in the Marico basin.

The Bushveld Granite weathers into picturesque knobs and koppies, more especially the variety traversed by well-marked joints known as "ball granite"; otherwise the country formed by it is undulating and sandy with scattered low outcrops and occasional small "tors."

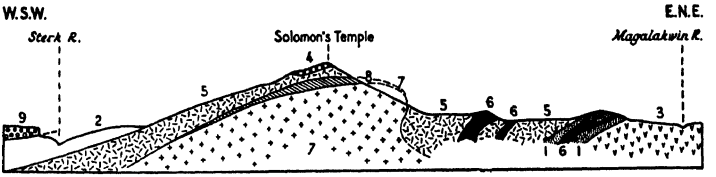


FIG. 29.—Section through the Zaaiplaats Tin Mining Area, 10 miles long (*adapted from* C. A. Strauss and F. C. Truter). 1, Rooiberg Quartzites, Hornfels, etc.; 2, Rooiberg Felsites; 3, Norite; 4, Granophyre; 5, Main Granite; 6, Porphyritic Granite; 7, Bobbejaankop Granite; 8, Lease Granite; 9, Waterberg System.

There were apparently several separate phases of intrusion that show gradational or sharp contacts and close with pegmatites. They range from pale pinkish to deep red, and from medium grain to porphyritic, and carry hornblende normally and biotite occasionally. A portion of the "Bushveld Granophyre" seems to be a marginal facies, though a part certainly represents highly recrystallised Rooiberg felsites and even quartzites.

That the Granite is *younger* than the Norite is indicated by the absence from along their junctions of any veins of norite in the former. On the contrary, between Potgietersrust and Zaaiplaats, and also to the north of Uitloop, dykes of coarse red granite traverse the norite, being sometimes granophyric, while at one place the norite has been shattered by and enveloped in red granite, the whole forming a *plutonic breccia*. A second fine instance of the latter is known from the east of Magnet Heights in the Steelpoort Valley. At the junction of the Steelpoort with the Mapochs River a large tongue of fine-grained

yellow-grey granite penetrates the norite, while other apophyses occur down the Kruis River Valley. North of Wonderfontein Station on the Belfast railway a broad body occupies a similar position, but is syenitic in character.

Petrography.[1]—An exceptionally wide range of types—from ultra-basic to ultra-acid—some of them unique, have presented themselves for study, secondary mineral alteration being fortunately slight as a rule.

(a) *Diabases.*—These are dark grey-green rocks, rather coarse in the grain and hence approximating to gabbro, weathering with a reddish crust, frequently spheroidally, and giving red or chocolate soils. They are mostly plagioclase-augite rocks with the pyroxene somewhat altered to greenish uralite, but at times approximate to diorite and then carry amphibole, as in a sheet just above the Daspoort Quartzite in the Marico area; ophitic structure can often be seen (Plate X, 2). (See Analysis No. 18.)

A sheet beneath the Magaliesberg quartzites in Pretoria consists of idiomorphic plagioclase, pyroxenes, green hornblende, biotite, quartz, and micropegmatite; the pyroxenes include enstatite and the rock thus approaches the norites. Intermediate phases with pleochroic rhombic pyroxene occur near to or at the base of the main body, for example, near Dullstroom and at Horns Nek and Hartebeestpoort north-west of Pretoria, passing insensibly into norite, thus proving their genetic connection.[2]

(b) *Norites and Gabbros.*—The prevailing type is a medium-grained, grey speckled rock of remarkably uniform character, rather like a granite in general appearance, but commonly showing a certain amount of orientation of the crystals of feldspar and pyroxene, through which the stone can be made to split along such planes. The norites are labradorite-diallage-bronzite (or hypersthene) rocks with a very little magnetite, biotite, and sometimes a little quartz; characteristic is the frequent intergrowth of the two forms of pyroxene (Plate X, 3). Certain kinds should strictly be called Gabbro, as the amount of orthorhombic pyroxene is distinctly low, particularly in the upper half of the mass, where the feldspar becomes more acid. Analyses are given under Nos. 20, 21, 22.

By reduction in the proportion of ferromagnesian minerals the rock passes through pale and "spotted" or "mottled" varieties with

[1] The more important recent contributions are:—B. V. Lombaard, *T.G.S.S.A.*, 1935, xxxvii, 5; B. Wasserstein, *ibid.*, 1937, xxxix, 215; G. S. J. Kuschke, *ibid.*, 1940, xlii, 51; H. J. Nel, *ibid.*, 1941, xliii, 37; W. R. Liebenberg, *ibid.*, 1943, xlv, 81; C. M. Schwellnus and J. Willemse, *ibid.*, 1944, xlvi, 23; C. A. Strauss and F. C. Truter, *ibid.*, 1945, xlvii, 47, in which earlier literature is cited.

[2] H. J. Nel, *ibid.*, p. 37.

occasional crystals of bronzite into almost pure plagioclase rocks—*anorthosites*—bands, veins, and streaks of which are common in the ordinary norite; an analysis is given under No. 19. The composition of the feldspar corresponds to about 80 per cent. anorthite. Sometimes bodies up to several hundreds of feet in thickness occur, as to the west of Wolhuters Kop Station and to the west of the Pilansberg, but they are widespread in the Critical Zone.[1] Coarse pegmatites composed of plagioclase and bronzite are not uncommon. Banded types in which layers of feldspar and pyroxene or seams of anorthosite, norite, and pyroxenite alternate are frequent and may be so finely developed, as in the Lulu Range in Sekukuniland, that the whole may come to resemble an ortho-gneiss.

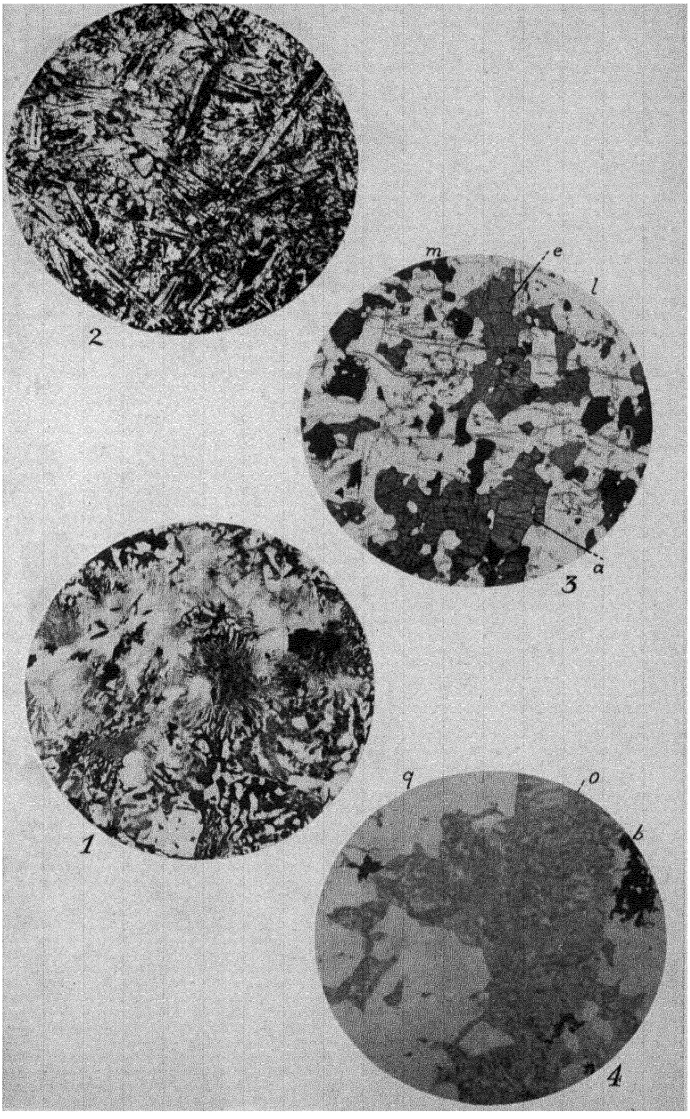
(c) *Pyroxenites and Peridotites.*—By decrease in the feldspathic constituent the norites pass through basic norites into pyroxenites, generally rather coarse-grained aggregates of orthorhombic pyroxene (bronzite or even hypersthene) with perhaps a little diallage, bytownite, and iron-ore. A foliated character is not uncommon, the optic axial planes of the orthopyroxene grains being generally perpendicular to such layering.[2] Noritic and pyroxenitic types may alternate on a large scale and so produce a marked "pseudo-stratification" accentuated by the presence of streaks or bands of magnetite and chromite, next to which a granular texture has been developed. (See Analyses Nos. 23, 24.)

Much less common, but normally absent from the Main and Critical Zones, are *peridotites*—olivine-pyroxene rocks—and *olivinites*—partly or completely serpentinised. They form bands or masses in the neighbourhood of the Pilansberg, on Mooihoek north of the Steelpoort (carrying chromite) and as dykes in the norite on Tusschenkomst and Welgewagd, both north of the Pilansberg.[3] The olivine is usually rich in magnesia in the Basal, and high in iron in the Upper Zone.

Remarkable both in east and west are the *hortonolite dunites*,[4] composed almost wholly of an olivine rich in iron, having a density of no less than 3·75 and occurring in the Critical Zone as sheets, lenses, or pipe-like bodies, certain of which carry platinum (see p. 538). (Analysis No. 25.)

(d) *Magnetite and Chromitite.*—Striking are the bands of *Magnetite* so characteristic of the Main Zone, following definite horizons in the norite sometimes for miles, and ranging from streaks to bodies 40 or more feet in thickness, as at Magnet Heights or Roos Senekal.

[1] A. L. Hall, *Union S.A.G.S.*, Mem. 21, 1924, 63.
[2] J. J. van den Berg, *T.G.S.S.A.*, 1947, xlix, 155.
[3] P. A. Wagner, *T. G. S .S. A.*, 1924, xxvi, 13.
[4] P. A. Wagner, *The Platinum Deposits and Mines of S.A.*, 1929, ch. vii; P. L. de Bruyn, *Ann. Univ. Stellenbosch*, 1944, xxii A. 63.



Photomicrographs of rocks from the Bushveld Complex. 1, Granophyre, Rooiberg Series; 2, Diabase, showing prisms of augite; 3, Norite, showing labradorite *l*, augite *a*, enstatite *e*, and magnetite *m*; 4, Red Granite, showing quartz *q*, orthoclase *o*, and altered biotite *b*. Each magnified 10 diameters.

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Successive bands are not unusual, associated with layers of pyroxenite and anorthosite. All transitions from norite to pure iron-ore can be found, and in those containing appreciable amounts of silicates the latter are sometimes finely idiomorphic, showing that the iron-ore was the last mineral to crystallise from the magma. The ores are invariably *titaniferous*, carrying from 8 to 24 per cent. of titanic acid, but are nevertheless strongly magnetic in places, due largely to fine intergrowths of ilmenite with magnetite or maghemite.[1]

The *Chromitite* bodies are of similar habit and occur mostly in pyroxenite, with the rhombic pyroxene largely altered to yellow "bowlingite," on various levels in the Critical Zone, and in places in the Basal Zone. The chemical composition of the chromite depends largely on that of the overlying silicate rock, from which it must have separated early (see p. 500).[2]

(e) *Red Granite.*—It is almost universally pink or deep red owing to the prevailing colour of the feldspar, which is often microperthite, *i.e.* an intimate intergrowth of orthoclase and albite-oligoclase ; indeed, the soda content is often somewhat high. Analyses are given in Nos. 30, 31, 32, showing a high silica content—72·5-75·8 per cent. Hornblende is the dominant ferro-magnesian mineral with subordinate biotite. Porphyritic varieties with large zoned orthoclases are represented, as at Rhenoster Kop to the north of Balmoral, but the bulk is a medium to coarse rock traversed by occasional finer-grained phases and by pinkish aplite (Plate X, 4). A granophyric texture is usual, especially near the intrusive junction with the felsites, where it may develop red pegmatites and pegmatitic quartz-veins and display secondary alterations, together with mineralisation, as recorded under Tin (p. 543).

In the Zaaiplaats area three separate ages of intrusive Red Granite have been detected, the types ranging from medium to porphyritic and pegmatitic, all of about the same chemical composition. The youngest phase has alone been responsible for mineralisation there,[3] a relation which might apply elsewhere. The *granophyres*, like those belonging to the felsites, are very dark red and rather resistant rocks with a much smaller proportion of dark minerals, and the groundmass is made of a delicate and beautiful micropegmatitic intergrowth of quartz and feldspar (exactly like that figured in Plate X, 1). Granite-porphyry dykes with granophyric groundmass cut the granite at Stavoren.

By reaction with quartzites " ultra-acid granites " have occasionally

[1] J. J. Frankel and G. W. Grainger, *S.A.J.S.*, 1941, xxxvii, 101.

[2] J. J. Frankel, *S.A.J.S.*, 1942, xxxviii, 152 ; C. F. J. van der Walt, *T.G.S.S.A.*, 1942, xliv, 79 ; C. M. Schwellnus and J. Willemse, *ibid.*, 1944, xlvi, 23.

[3] C. A. Strauss and F. C. Truter, *T.G.S.S.A.*, 1945, xlvii, 47.

been produced, though most of the types so-called are highly altered sediments. Where the granite has invaded the norite a modification has sometimes been brought about due to reaction, and transitional types have been evolved, some of which can be described as monzonite-porphyries, as, for example, at the southern end of the Sekukuni Mountain. Certain syenitic varieties penetrating the norite—dark rocks with orthoclase, hornblende, and very little or no quartz—such as in the belt north of Wonderfontein Station on the Belfast railway, have perhaps resulted from similar interaction in depth.

Magmatic Differentiation.—Much light has been shed on this subject by intensive field study backed by numerous analyses. The various rock-types all seem derivatives from one parent magma close to that of the volcanics and sills in the Pretoria Series, which have a composition near the *average* of all the Bushveld rocks. Under orthodox views *the Norite and the Red Granite are essentially the basic and acid poles of primary differentiation.* The lower or "*chill phase*" of the Norite is usually transitional to the subjacent diabase and approximates to that of the hypothetical parent magma, while the upper or "*roof phase*" tends towards the granite. The ultra-basic and chromiferous types occur well up in the norite, the ferriferous and titaniferous ones higher still. Traces of such elements as Cr, Ti, and V occur throughout its mass.

The feldspars of the anorthosites and the pyroxenes of the pyroxenites have about the same composition as in the accompanying gabbros. Proceeding upwards in the norite the pyroxenes include less of the orthorhombic variety and carry less iron but more magnesia, the plagioclase shows decrease of the anorthite molecule, while hornblende appears at the top. This suggests that the pseudo-stratification was due essentially to the rhythmic precipitation of crystals—including remelting in certain cases—from successive "heaves" of magma of progressively changing composition, whereby the laccolith was fed and its cover raised. This receives support from the study of the chromitite bands. Such layering, although fine, is moreover persistent, the Merensky Reef having, for example, been traced over hundreds of miles, and many of the chromitites over long distances. Although Hall regards the sagging of the floor as due to the emplacement of the basic magma, the fact that such mineral banding displays the same regularity irrespective of the present dip indicates that it was produced in approximately *horizontal position*, for which view the cross-cutting dunite "parsnips" provide confirmation. The basining was presumably *subsequent on the whole* to the consolidation of the norite. The Red Granite is a residual magma deficient in lime and magnesia but rich in iron and with affinities towards the alkalic rocks. The various granophyres and felsites show close similarities in their compositions.

Striking are the remarkably close correspondences, even in details, between the igneous complexes of the Bushveld, Stillwater of Montana, " Blow-me down " of Newfoundland, Duluth of the United States, and Sudbury of Canada.

Metamorphism produced by the Complex.[1]—The outstanding features in regard to the alteration of the Pretoria Series are, first, the gigantic scale of the phenomenon and, secondly, the little disturbed nature of the altered strata. The metamorphism of the floor appears to have been effected essentially by the overlying compound cake of plutonic rock, and more particularly by the earlier norite, though the influence of the numerous and often thick sheets of diabase in the foundation has in certain parts been considerable. The alteration extends a vertical distance downwards ranging from a few hundreds of feet, *e.g.* at Pretoria, to many thousands, *e.g.* at Zeerust. The rocks forming the roof were less affected, being chiefly felsite and quartzite, though the latter, through regenerated or introduced feldspar, has in places been converted into rocks almost or quite indistinguishable from granite.

(a) *Shales.*—Since argillaceous rocks are very susceptible to thermal influences, the variations in the intensity and nature of the alteration are displayed most satisfactorily in the three shaly members of the Pretoria Series.

The first or lowest grade of metamorphism, developed farthest from the Complex, has given rise to the LONGSIGHT TYPE of product, in which the original shaly character of the rocks, their bedding planes, etc., are still recognisable, although crystals of various contact minerals are often quite conspicuous, such as chiastolite or andalusite, ottrelite, and some mica (Plate XI, 1); staurolite may be present, while cordierite and tourmaline are rare. Such rocks constitute the *outer or chiastolite zone*, as is finely developed west of Ohrigstad and around the western end of the Basin.

The product of the second grade of metamorphism is the GROOTHOEK TYPE, in which the original sedimentary characters of the rock are no longer obvious in the hand-specimen, the beds having been altered to a hard, crystalline, grey or black material with granular texture and glittering appearance due to abundant minute flakes of biotite. The thin section shows biotite, cordierite, quartz, tourmaline, andalusite, muscovite, garnet, and sometimes staurolite—in this

[1] The problem, which is distinctly complicated, has been fully discussed by A. L. Hall, *T.G.S.S.A.*, 1908, xi, 1; 1909, xii, 119; *Proc. G.S.S.A.*, 1915, xvii, 22; *Union S.A.G.S.*, 1932, Mem. 28, chap. xi.

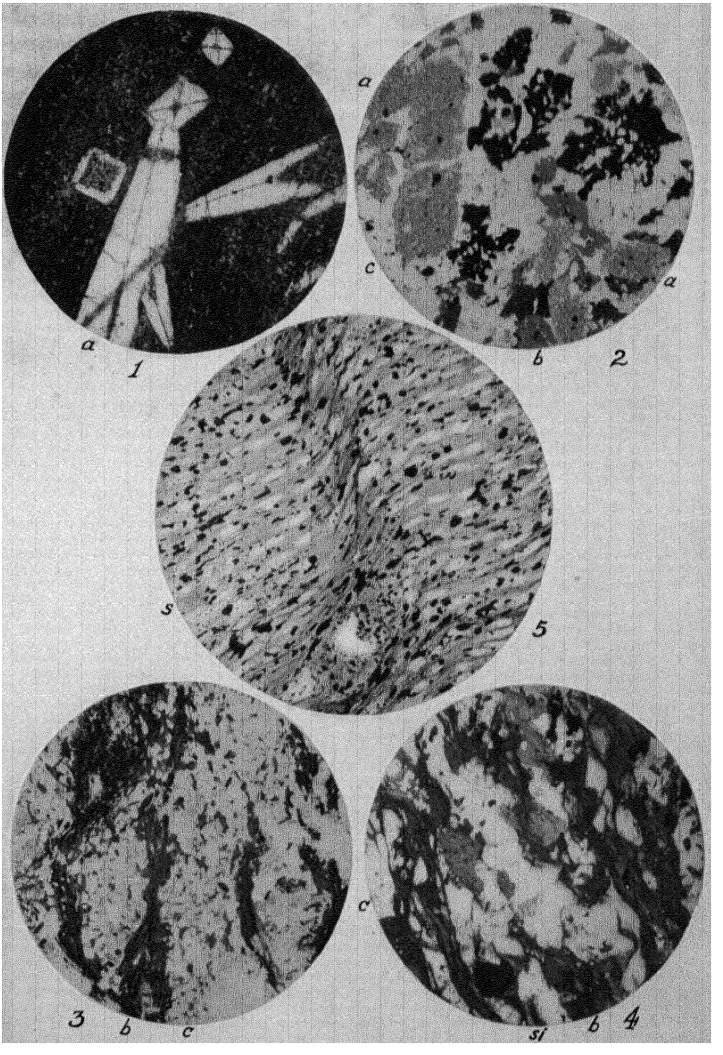
relative order of abundance—" sieve texture," in which the large crystals are riddled with tiny inclusions, being very characteristic (Plate XI, 2). Such rocks can be called *hornfelses* (or cordierite hornfelses) and constitute the *inner or hornfels zone*, which is quite constant round the eastern and western curves of the basin. Actually, there is no perfectly sharp division between these two types, which pass by degrees one into the other.

A third kind, the MALIPS RIVER TYPE, found in the extreme north-east in M'Phatleles Location, embraces in its most altered form schistose and even gneissose rocks containing abundant brown and white mica, while the thin sections show also cordierite, sillimanite, zircon, tourmaline, etc., set in a mosaic of quartz and feldspar (Plate XI, 3, 4). These remarkable rocks, into which the Groothoek type may pass by degrees, are practically identical with certain of the crystalline schists and para-gneisses in the primitive systems the world over, and can therefore be termed *schists* or *gneisses*. They have been produced under *Dynamic Metamorphism* within a belt of crumpling that trends eastwards from Chunies Poort, clearly at a late stage. This alteration has extended right down through the Daspoort quartzites into the Banded Ironstones and Jaspers with considerable recrystallisation. The Longsight and Groothoek types, on the contrary, represent degrees in intensity in *Thermal* and *Static Metamorphism*. In the region containing the Malips River type the Daspoort quartzite has been changed to a quartz-sericite schist (Plate XI, 5).

(b) *Quartzites.*—Obviously such refractory rocks would not lend themselves to much alteration, but the Magaliesberg horizon and various strips of quartzite enveloped in the Norite to the north of Pretoria and elsewhere have been converted into coarse-grained rocks with exceptionally large interlocking areas of quartz, together with some iron ores and perhaps a little mica. This has been called the DOORNPOORT TYPE.[1]

At Stavoren a zone in the invading granite is crammed with fragments of the overlying quartzites, with the production of a thick injection-breccia. Certain so-called " ultra-acid " rocks simulating granites and granophyres, formerly supposed to be purely igneous, are recrystallised Rooiberg feldspathic quartzites.[2] They form a zone along the west bank of the Nyl, some hundreds of feet thick, lying between the norite below and the granite above, and occur again from the Zebedielas River to the Sekukuni Mountain. Appearing as coarse rocks with quartz, pinkish feldspar, some iron-ores, but little else, their sedimentary origin is betrayed by ripple-marks or traces of false-bedding, for example, those of Adriaanskop, while their zircons may

[1] A. L. Hall and A. L. du Toit, *T.G.S.S.A.*, 1924, xxvi, 69.
A. L. Hall, *T.G.S.S.A.*, 1922, xxiv, 228.



Contact Rocks in the Pretoria Series. 1, Chiastolite Slate (Longsight type), showing crystals of chiastolite; 2, Cordierite contact-rock (Groothoek type); 3, Mica schist (Malips River type); 4, Cordierite contact-gneiss (Malips River type); 5, Sheared Daspoort Quartzite; *a*, andalusite; *b*, biotite; *s*, sericite-mica; *c*, cordierite; *si*, sillimanite. Magnified 14 diameters.

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have shapes like those of sediments.[1] Near Potgietersrust, Rooiberg quartzites have been crystallised to " leptites " with production of intrusion-breccias.[2]

(c) *Calcareous Strata.*—Tremolite in needles, accompanied by wollastonite, is common in the top of the Dolomite towards the western end of the Basin, for example to the south of Zeerust. At the Uitloop Limeworks, north of Potgietersrust,[3] contact with pyroxenite has produced rocks composed of olivine (forsterite)—generally altered to serpentine—diopside, garnet, calcite, and dolomite, and these locally display a peculiar type of " dedolomitisation," an action that has also to be invoked to explain the low magnesium content of the white crystalline marble in the huge mass of " dolomite " enclosed by the plutonics on Marble Hall. Calcareous bands of varying composition from horizons below and within the Magaliesberg Group have been described from a number of points near Potgietersrust, Sekukuniland, and along the north of the Magaliesberg, ranging from marmorite to hornfels and carrying varying amounts of wollastonite, diopside, andradite garnet, plagioclase, calcite, spinel and quartz, and sometimes actinolite.[4]

(d) *Other Cases.*—The Pretoria lavas and tuffs have in extreme instances become re-crystallised into hornblende granulites. In the case of xenoliths transfusion has sometimes occurred with the production of " contaminated " products.

Transfusion Hypothesis.—This has been developed by Dr. van Biljon,[5] who has pointed out that in the Premier Mine area, where the Pretoria succession is complete, the Magaliesberg Quartzite stage is of great thickness, even allowing for possible duplication, and that it is invaded merely by diabase. From thence not only does its base run regularly westwards but its top as well, the latter defined by quartzite strips that hug the norite-granophyre contact. Towards the west there would seem to have been an actual replacement of sediments by an approximately equal thickness of noritic rocks retaining considerable quartzite belts as relics. South of Marikana more of the lower quartzites have survived.

Suggestively, to the west in Rustenburg and north-east in Lydenburg, the metamorphism was stronger, affecting even the

[1] C. A. Strauss and F. C. Truter, *T.G.S.S.A.*, 1945, xlvii, 47.
[2] C. A. Strauss, *T.G.S.S.A.*, 1944, xlvi, 39.
[3] R. B. Young, *T.G.S.S.A.*, 1916, xix, 57.
[4] A. L. Hall, *T.G.S.S.A.*, 1909, xii, 124; S. van Biljon, *ibid.*, 1937, xxxix, 45.
[5] *T.G.S.S.A.*, 1949, lii, 1-197.

underlying Daspoort stage. Rheomorphic action, marked at the base of the lopolith, is intense at its summit, where the Rooiberg quartzites and felsites have been extensively converted into "granites" and "granophyres" retaining unquestioned sedimentary structures, with a wide mineralisation. In the heart of the Complex the Magaliesberg beds appear to have been transformed on a huge scale into pseudo-igneous rocks of basic and ultrabasic composition. Such conversion would demand vast amounts of ascending hot mineralisers bringing in alkalies, alumina, etc., and providing the heat needed for the postulated reactions. The shales were transfused into norite, and carbonate-rich layers into basic and ultrabasic rocks that have retained to a surprising degree their original bedding, perpetuated in pseudo-stratification. Transitional stages stand revealed by extensive xenolithic zones of exceptional mineral composition.

Volatiles, rich in Fe, Ti, Cr, F, Pt, etc., and charged with CO_2 from the Dolomite as well as HO_2 and salts from the strata attacked, are deemed to have converted carbonate bands into those remarkable and widespread seams of magnetite, chromitite, platiniferous diallage-norite, etc., and that quite independent of the attitude of the strata. The metasomatic nature of the Potgietersrust platinum deposits gives support to this view. In such transfusion ionic exchanges are held to have played a vital part. The quartzose types proved the most resistant, wherefore the number and size of such recrystallised xenolithic bodies preserved undigested in the norite—with marked acidification within the latter—but their scarcity in the Red Granite.

The Bushveld Basin is accordingly viewed as a cauldron within which floods of mineralisers were erupted that transformed strata, from the Dolomite up to the Felsites, into quasi-igneous products, perhaps largely while in the solid state. Wherever selective liquefaction became possible, true magmas were generated that could travel upwards and outwards—mainly as sills of diabase and granite. Significantly, certain eminent petrographers have come to regard the noritic suite as derived from contaminated magmas.

While revolutionary, this hypothesis seems competent to meet not a few of the serious difficulties experienced under current theories involving magmatic differentiation, such as the persistent, even, fine, and rhythmic mineral-banding and other curious structures, particularly in the Critical Zone, its high dip in places,

the concentration of the iron ores not at the base of, but high up in the Norite, the sheet-like habit of the Red Granite at the summit, and so forth. Assuming in current fashion that the quartzites were not replaced by, but merely interleaved with, norite magma, it becomes necessary to explain the absence over long stretches of the top portion of the Magaliesberg Stage, for which a process of sinking into the basic melt could hardly be invoked.

C. Occurrences outside the Bushveld Basin

On the farm Blaauwbank south-west of Magalies Station the Timeball Hill shales are invaded by a small mass of pyroxenite that has converted them into silvery schists veined with quartz, proved to be auriferous and formerly worked. Another tiny body of norite and pyroxenite with iron-ore pierces the Ventersdorp lavas on Kaffirskraal west of Heidelberg. On Nooitgedacht, south-west of Balmoral, a large mass of Red Granite crops out in the Pretoria beds (and diabase), coarse and massive in the centre and red and fine-grained at the periphery. Just outside the north-western edge of the Basin and penetrating the Ventersdorp lavas at several points along a belt from a point east of the Marico River to Crocodile Pools [1] are a number of masses of basic and acid plutonic rocks which, being largely hidden by soil, are probably more extensive and continuous than the mapping would indicate. Diorite, gabbro, norite, and pyroxenite—foliated in places—together with some bands of magnetite recall the Bushveld assemblage, which is strengthened by the presence of a red, medium to coarse granite, sometimes containing microcline, sometimes granophyric.

First noted by Molyneux [2] along the railway west of Mochudi Stad, there extends from that point westwards past Gaberones to Kanya and near Lobatsi a pale red to purple-red non-foliated porphyritic granite. This is bounded on north and south as well as partly roofed by Ventersdorp quartz porphyry and felsite unconformably followed in places by Waterberg sandstone. Since Wagner [3] has reported flesh-coloured granite intrusive in the Dolomite and in the diabase cutting the latter a little north of Kanya, the Gaberones Granite may be of Bushveld age. In its relation to the unquestioned Ventersdorp effusives the writer has, however, found, in addition to intrusive contacts, sections in various localities showing complete transitions between the two formations through the medium of pinkish granophyric types. The

[1] *Union S.A.G.S.*, 1920, Expln. Sheet 14 and 15.
[2] *Proc. Rhod. Sci. Assoc.*, 1907, vi, 73.
[3] *P.G.S.S.A.*, 1930, xxxii, p. xlviii.

possibility is hence not excluded of some of the granite being the plutonic equivalent of the felsites and therefore of Ventersdorp age. Syenite and granophyre pierce the Griquatown beds in the Doornberg not far from Prieska.

(*a*) **The Great Dyke of Rhodesia.**[1]—Outstanding in more than one sense is the colossal dyke-like intrusion of basic and ultrabasic rocks with a width of from 3 to 6 miles, that runs nearly straight in a direction a little east of north from Belingwe for over 300 miles with a curious hooked termination where its continuity is interrupted at two points, and reaching to the edge of the Zambezi Valley. Rising from 200 to 1000 feet above the level of the granites and schists on either side and making rough dark outcrops, it gives rise to the Doro, Selundi, Mhlaba, and Umvukwe ranges in different parts of its course. There is much cross-faulting.

The rocks consist essentially of peridotites, pyroxenites, and norites together with associated types exactly like those of the Bushveld Complex, much of what has been said about the latter applying here. Instead, however, of the basin-shaped structure, the pseudo-stratification is *synclinal*, that is to say dipping inwards from either margin, steepest next the edges and flattening towards the centre-line (Fig. 30). The normal arrangement is :—peridotite

FIG. 30.—Generalised section across the Great Dyke. G, Granite and Gneiss; S, Serpentine; E, Enstatite Rock; N, Norite; c, Chromitite Seam; p, Platiniferous Horizon.

below followed by and often alternating with pyroxenite—both serpentinised locally—crowned by greyish norite, in places feldspar-rich. Pseudo-stratification is well-marked at numerous points along its length. Owing to erosion the norite capping has only been preserved over stretches in the Shabanie, Selukwe, and Umniati-Hunyani sections, and in abnormal position in the Makura Hill in the extreme north. No trace of a roof has yet been found.

[1] P. A. Wagner, *T.G.S.S.A.*, 1914, xvii, 49; A. E. V. Zealley, *T.R.S.S.A.*, 1915, v, 1 (giving photomicrographs); *S. Rhod. G.S.*, Bull. 3, 1919; F. E. Keep, *S. Rhod. G.S.*, Bull. 16, 1930; B. Lightfoot, *P.G.S.S.A.*, 1941, xliii, p. xxvii (citing earlier literature); O. Weiss, *T.G.S.S.A.*, 1941, xliii, 143.

Of economic importance are the layers of black *chromitite* from 3 to 12 inches thick and from one to seven in number, usually in the peridotites, that dip inwards on either side of the Dyke at angles of from 10 to 40 degrees and are widespread. Thin bands of chrysotile asbestos are not unusual as well, *e.g.* the Ethel Mine. Shortly—commonly from 20 to 60 feet—below the base of the norite may lie a zone from 3 to 10 feet thick of pseudo-porphyritic diallage norite carrying sulphides and platinum, traceable in outcrop by copper and iron-staining, thus paralleling the Merensky Reef of the Bushveld (p. 190); this horizon seems to be widespread.

The habit of the intrusion cannot well be made out since its margins are almost invariably obscured by vlei-soil. In a few places the Old Granite seems to pass beneath the basic edge, as on the Umgezi River in the Belingwe district; in others the contact appears to be almost vertical. Where cutting across a schist-belt, xenoliths thereof may have become included. Along the margins some talc schist may appear—probably due to volume changes in the borders of the intrusion during or after consolidation.

Gravimetric and magnetometric measurements dispose of many conjectures by indicating a symmetrical dyke-like body of heavy rock tapering downwards to unknown depths, its core having a mean density of 3·3. For this extraordinary type Weiss has suggested the name "*abyssolith.*" Crystal stratification must have taken place in the upper part of the magma column, followed by sagging along the axis, where the cooling would have been slowest. Underground the Dyke must be prolonged towards the south, as shown by detached dykes of pyroxenite, while it is paralleled to the west in the Insiza and Selukwe districts by a prominent dyke of quartz-enstatite diabase or norite having a composition identical with that of certain intrusions in the Bushveld (Keep), and is cut by dolerite dykes and shifted by transverse faults.

Petrographically the rock types resemble strikingly those of the Bushveld and like them are clearly the products of a basic magma under differentiation, exhibiting a sequence from a feldspar-rich norite through pyroxene-rich varieties to pure pyroxene rocks (spec. grav. 3·3—Zealley). In lesser amount come websterites—enstatite-diopside rocks—and poikilitic hartzburgites with olivine crystals enveloped by large pyroxenes, together with chromitites carrying idiomorphic chromite. (See Analyses Nos. 26, 27.) Veins of granite are common within and usually parallel to the basic margins of the Dyke, which have usually been taken to represent the acid residue from the crystallisation of the Complex.

(*b*) **The Vredefort Mountain Land or Vredefort "Dome."**[1]—The phenomena associated with the singular ring of strata upturned around the Vredefort-Parys Granite are indeed remarkable, and led Molengraaff and Hall to the conclusion that this region displays a unique manifestation of the Bushveld magmatic activity.

Partly concealed by Karroo beds, it was supposed to be quite circular, but geophysical measurements have suggested a pear-shaped outline with longer axis trending N. 32° W. (Maree). Surrounding the central "core" of Old Granite 25 miles across are arranged practically the whole of the Witwatersrand, Ventersdorp, and most of the Transvaal systems to a total thickness of some 40,000 feet.

Not only have these strata been tilted up to high angles generally, but over the north-western half of the periphery they have been strongly overturned so that the beds there dip regularly, *though in inverted order, towards the centre* at angles that are often only 50-60° and in a few places so low as 40°. On the east and south-south-west the dip becomes normal although steep, but for the concealed south-eastern side lower inclinations have been deduced. The Witwatersrand beds, especially on the north-west, are criss-crossed by faults in which the basic (Bushveld) sills have shared.

Altogether over a sharply defined area 55 miles wide an extraordinary updoming of both the granite and the overlying beds has taken place to the extent of many thousands of feet, producing an asymmetrical mushroom-like structure, the core having apparently behaved like a gigantic punch, developing tangential, radial, or curving planes of fracture and shear in the yielding cover, along which basic magma rose in a complicated network. As the result metamorphic minerals—both *stress* and *contact*—such as hornblende, garnet, andalusite, cordierite, staurolite, etc., were developed in roughly concentric zones in the north-western sector. The dynamical is believed by Hall to have preceded the thermal metamorphism.

The evidence points furthermore to the introduction of a large body of magma excentrically beneath the updomed area, somewhat to

[1] G. A. F. Molengraaff and A. L. Hall, *Hand. Kon. Akad. Wiss. Amsterdam*, 2 sect., pt. xxiv, 3, 1925; E. B. Bailey, *Geol. Mag.*, 1926, 481; L. T. Nel, *Union S.A.G.S.*, 1927, "The Geology of the Country around Vredefort," Expln. Sheet 61, 1939; H. Cloos, *Geol. Rundsch.*, Bd. xxviii, 3-4, 1937, 253; D. W. Bishopp, *T.G.S.S.A.*, 1942, xliv, 1; B. D. Maree, *T.G.S.S.A.*, 1945, xlvii, 183; R. A. Daly, *Journ. Geol.*, 1947, lv, 125.

the north-west of its centre, conferring an additional (thermal) metamorphism upon that due to mechanical upthrusting (dynamical), whereby Lower Witwatersrand beds were through an immense thickness converted into coarse-grained andalusite-cordierite hornfels, garnet-amphibole hornfels, and other remarkable rocks. At three points offshoots from this presumed reservoir are now exposed in the bosses of *alkali granites* piercing the Witwatersrand beds at Witbank and Schurwedraai on the Vaal River, and the Dolomite at Rietfontein more to the north, each accompanied by dykes of nepheline syenite (Fig. 12). The Old Granite has even experienced modification, being streaky and decidedly red in many places. Extraordinary is the abundance of the so-called " flinty crush-rocks " traversing alike Old Granite, the Witwatersrand, part of the Ventersdorp and even the alkaline intrusions, but especially the first, in irregular and generally reticulating dykes, seams, and threads. Termed "*pseudotachylite*" by Shand,[1] this black material is usually crowded with fragments of the rock within which it occurs. Thin sections reveal all gradations from opaque stuff to crystalline fine-grained material, though the groundmass is never completely isotropic. A state of fusion has therefore been disputed by Willemse.[2] They mark, it has been asserted, the culmination of the updoming process, when the structure shattered and material ground up along lines of crush into the condition of " mylonite " became locally fused, and was even injected into the adjacent rock.

Age and Origin.—The general dating of this structure is unproved—far less its several phases. Molengraaff and Hall have stressed the resemblance of the cycle of igneous activity to that of the Bushveld and favoured a similar or slightly later age. Truter [3] has on the contrary given cogent arguments for a post-Waterberg age, particularly the presence of the associated alkali-complex and the fact that pseudotachylites have been produced in the latter and in the gabbro sills, a view supported below.

Every attempt to explain the mechanism of this amazing structure has come up against some insuperable obstacle. Molengraaff and Hall have postulated symmetrically convergent or centripetal pressures, Bailey and Bishopp centrifugal pressures produced by the upthrusting of the quasi-plastic central Old Granite with the overturning of its sedimentary " collar." The assumption, as hitherto, of a mushroom-like outline involves, however, an impossible height for the rising dome, coupled with horizontal and vertical pressures vastly in excess of isostatic principles.

Not only is the Dome centrally and intimately related to the

[1] S. J. Shand, *Q.J.G.S.*, 1917, lxxii, 198.
[2] J. Willemse, *T.G.S.S.A.*, 1938, xl, 43.
[3] F. C. Truter, *P.G.S.S.A.*, 1942, xliv, p. lxxxiv.

widespread orogenic arcs (Fig. 32), but it is at least half-encircled by a chain of parasitic domes and basins (Sheet No. 61). That it was a centre of potential sub-crustal weakness is disclosed by Willemse's studies. From geophysical survey Maree has deduced a marked asymmetry with extensive inversion on the north-north-west side, and a buried heavier mass near the centre. Structural analysis indicates that the Vredefort " nucleus " must have been driven northwards between narrowing jaws on both east and west until even the southern rim of the Bushveld Basin became indented. Such a focal position points to purely tectonic agencies, and excludes the fantastic view of meteoritic impact proposed by Daly.

The essential point to note is the fact that the Bushveld igneous activity was succeeded by deformation and intense erosion, that presumably extended over the Vredefort area as well, by the deposition of the Waterberg beds up to limits not yet defined, and by the buckling of those strata along roughly east-west arcs following the older lines. The second is that the " roof " must have been thin enough to yield—and this despite the enormous thickness of the rocks involved—which in turn demands fundamental assumptions of unusual kind, with the abandonment of current ideas of " single-stage " doming. With full realisation of its weaknesses, the following tentative scheme is submitted :

(1) Development within the Vredefort area during late or post-Bushveld Complex times of a normal structural dome, and its considerable erosion (Fig. 31, A). (2) Its partial or complete burial beneath Waterberg beds, with some overlapping by the latter (Fig. 31, B), if the next assumption be conceded. (3) Centripetal migration of sub-crustal magma beneath the progressively rising dome. (4) Development of post-Waterberg crustal pressures from the south under which the entire Vredefort block was impelled northwards—compressed frontally, laterally, and posteriorly—with the production of an asymmetry. (5) Low-angle thrusting around the margin of the bulging and constricting core (Fig. 31, C). (6) Slicing-off of the roof by major thrust-planes largely following the base or bedding of the Waterberg cover, and its displacement towards the north (Fig. 31, D) with overloading of the curving Potchefstroom syncline, inversion, and intense metamorphism of the Lower Witwatersrand beds on that side, attended by abundant minor adjustments in and around the core. Such thrusting was, moreover, widespread—to Potchefstroom, Gatsrand, and Pretoria. (7) Sub-crustal magma-transfers with intrusion of alkali-granite, followed, after all major movement had ceased, by the Pilansberg dykes, introduced in the position of least pressure. (8) Prolonged pre-Karroo erosion that removed not only the thrust-masses, but some part indeed of their floor.

One of several variants of this scheme visualises after Fig. C the rising of the granite body causing the cover to rupture, slide off—mainly towards the north-north-west—thus promoting up-doming,

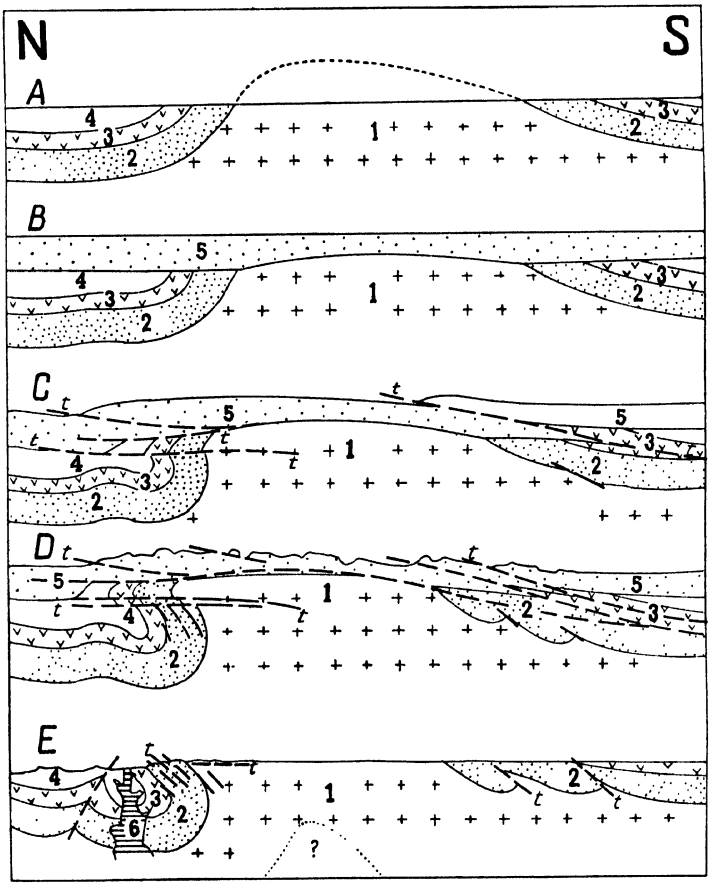


FIG. 31.—Stages in the formation of the Vredefort Dome. 1, Old Granite; 2, Witwatersrand System; 3, Ventersdorp System; 4, Transvaal System; 5, Waterberg System; 6, Alkali Granite; *t*, Thrust Fault.

as well as erosive attack. The roots of such hypothetical thrusts should lie beneath the Karroo beds to the east of Kopjes, where less disturbed Witwatersrand beds have been proved by borings. As support for this concept the Old Granite north-east of Parys is found

to have been *thrust horizontally* over tilted Witwatersrand beds, while flat sills of rather fresh gabbro are not uncommon in that quarter, hinting that this hypothetical plane of overthrusting could have run not far above the present surface.[1] Now that the alkaline suite is known to be of post-Waterberg age, the concealed heavy body beneath the Parys granite might consist of gabbro-foyaite-syenite, from which the alkali-granites could have been derived. Acceptance of a post-Waterberg age will bring the Vredefort tectonics into harmony with those of the Cape-Transvaal region (p. 23) and explain this extraordinary structure as due to a localised torsion developed ahead of, and finally overrun by, a widespread convergent crustal creep.

Economic.[2]—While the " mineral province " of the Bushveld is the largest of its kind in the world and contains colossal amounts of platinum, chromite, and magnetite in the Norite, its economic importance should not be overrated. Platinum and chrome ore are being produced on a considerable scale and will continue to be exploited. The bulk, however, consists of tin in or connected with the Red Granite. The gold occurrences consist of quartz veins along its southern margin, together with the remarkable gabbroidal intrusion, carrying metallic gold and some telluride, mined at Waaikraal, Rustenburg.

Among the other associated minerals that are being mined are vanadium ores and fluorite. It is not unlikely that the minute scrutiny which the Complex is receiving will lead to the discovery of other useful minerals.

[1] *Union S.A.G.S.*, Expln. Sheet 61, Figs. 3 and 4.
[2] See A. L. Hall, *Union S.A.G.S.*, 1932, Mem. 28, ch. xv.

CHAPTER IX

THE MATSAP, WATERBERG, AND UMKONDO SYSTEMS

Matsap. Waterberg. Umkondo. Tectonics. Correlation. Intrusions. Alkaline Rocks.

THESE three possibly equivalent formations are peculiar through their predominantly arenaceous character and brownish, reddish, or purplish colouring. Furthermore the first two are younger than the Transvaal System, and the third than the Lomagundi System. Although not capable of proof, they are believed to be older than the Cape System, and consequently *pre-Devonian*. Not improbably they may prove to be of pre-Nama age.

If the above correlations prove correct, they must have formerly covered a vast region—one over 500 miles wide and 1000 miles long (Fig. 32). Reposing upon a variety of formations, a profound erosion-period preceded their deposition, which was terminated by intense orogenic movements within certain belts.

[*Editor's Note.*—During the past few years, doubt has been thrown upon the correlation of the Matsap with the Waterberg. From a consideration of tectonic evidence Haughton (*T.G.S.S.A.*, 1950, liii, 205) has suggested that the Matsap System is pre-Waterberg, a suggestion supported by field evidence noted by H. B. S. Cooke in the Bechuanaland Protectorate. The further suggestion has been made that the Matsap beds should be correlated with the Loskop beds, as defined by F. C. Truter, and the Waterberg System considered the continental equivalent of the Nama System.]

A. The Matsap System

Distribution. Lithology. Lower Beds and their Base. Middle Beds. Upper Beds.

Thus entitled by Stow in 1874 from the " pan " of that name one degree north of Prieska, which is bounded on the west by these rocks, the formation consists of a group of quartzites and grits which, owing to their hardness, build up prominent chains of bare, stony hills.

Distribution.[1]—The known exposures fall within an arc running from a little south of the Orange River northwards into the Bechuanaland Protectorate, a distance of fully 250 miles; but, while attaining a maximum breadth of 75 miles, the rocks therein occur largely as isolated ranges with general north-south trend rising out of an ocean of Kalahari sand (Plate XII).

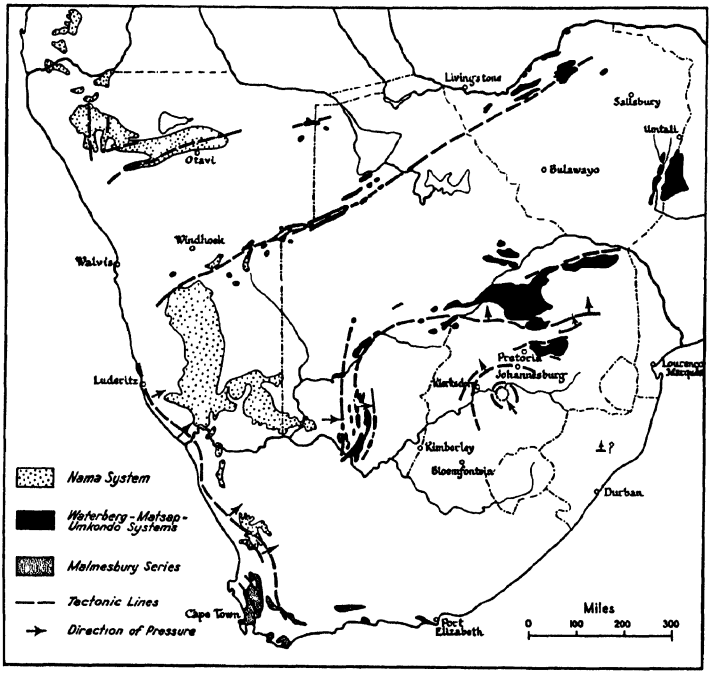


FIG. 32.—Outline Map to show the Distribution and principal Tectonic Lines of the Waterberg-Matsap-Umkondo Systems with regard to the Malmesbury Series and the Nama System.

In the east, where their base rests on the Griquatown beds, the dips are westwards and moderate, but as one proceeds westwards they are found to show progressively more and more disturbance, ultimately displaying close folding and even overturning towards the east, accompanied by strong cleavage

[1] *Ann. Rep. G.C. for* 1899, 82; 1905, 190; 1906, 50; 1907, 60; 1908, 89. D. J. L. Visser, *T.G.S.S.A.*, 1945, xlvii, 197; *Union S.A.G.S.*, 1938, Expln. Sheet 173.

(Fig. 24). The folding becomes open and regular again to the west of the Langebergen, where the System must rest upon the Kheis quartzites and schists.

The Ezel (Esel) Rand constitutes the southern end of this belt and the beds are continued across the Orange River, making bare linear ranges rising from 1000 to 1500 feet above the adjacent country with a multitude of minor hills, more especially on the eastern side, each with its base disappearing beneath plains of red sand. The two southern sections are known as the Langebergen, the northern of which attains the altitude of 6011 feet above sea-level and is duplicated to the west by the Sagoup Range with its continuation northwards into the Kalahari made by the Korannaberg. To the west stand out the isolated Scheurberg, Inkruip, Kamkuip, and Karreeboom hills.

Numerous borings have proved these beds to have a wide distribution beneath the universal covering of sand. To the north these quartzites, strongly folded along north-south axes, are exposed in the trough of the Molopo at Kuis, overlain by the Dwyka tillite, and project again in the Protectorate around Tshabong with gentle undulations that strike north-eastwards towards the Waterberg outcrops near Kanya (p. 210). An inlier in a pan between Tshabong and Lehututu serves to support Rogers[1] in his opinion of a Matsap age for the purplish-red quartzites and " greywackés " and occasional shales in the Ghanzi district in the central Kalahari, a formation originally called the " Chanse Beds " by Passarge.[2] Seen from the air, they are folded along axes directed west-south-west. Westwards they extend through Olifants Kloof into South-West Africa and are widely developed about Gobabis and to the east and south of Rehoboth. At Dordabis they are folded against supposed Nama beds and they may possibly pass beneath the Nama of the Naukluft area. Eastwards they reappear along the southern side of Lake Ngami dipping at moderate inclinations southwards and carry pebbles of the quartz porphyry of the Kwebe Hills nearby, include shales and dark crystalline limestones and may perhaps be associated with certain basic lavas, breccias, tuffs, and quartzites.

Lithology.—Consisting mainly of quartzites, grits, and sandstones with occasional conglomerates, their outstanding characteristic is the predominantly purplish, lilac, or reddish-grey colouring, bluish on freshly exposed surfaces, making them conspicuously different from any other formation in the Cape

[1] A. W. Rogers, *T.R.S.S.A.*, 1935, xxiii, 165.
[2] S. Passarge, *Die Kalahari*, 1904, ch. xxxii.

Province, rendering them recognisable with certainty as erratics in the Dwyka tillite. Some of the grits are striking in carrying, in addition to rounded bluish quartz grains, particles of brilliant red jasper like that in the Ongeluk volcanics, while the conglomeratic bands commonly contain pebbles or lumps of Griquatown ironstones as well. Certain layers are auriferous. The softer strata are pinkish, cream, or white sericitic quartzites and slates, though always in subordinate amount.

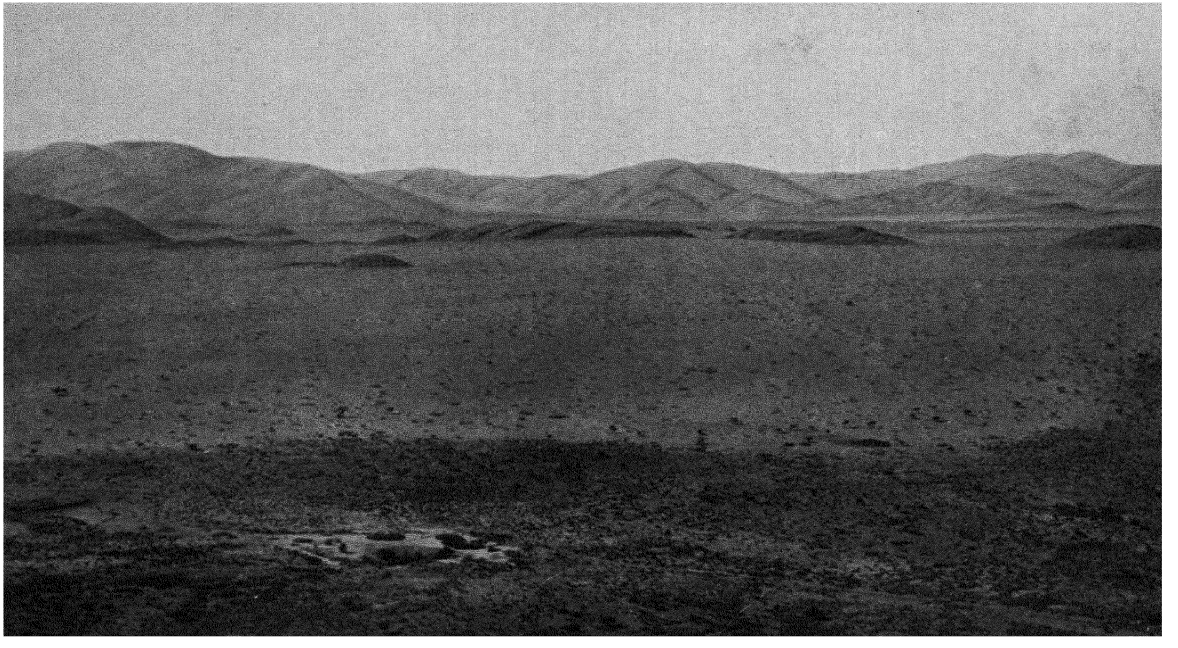
The considerable folding, coupled with the absence of recognisable horizons, prevents accurate measurement of their thickness, but where fully developed the System probably has a value of 10,000 feet.

On the eastern side of the Langebergen the succession can be triply divided by means of a thick group of volcanic rocks, mainly lavas, together with tuffs and intercalated sediments, which have, however, not been recognised to the west of that range, having probably thinned out in that direction.

The Langebergen seem to mark the site of a *geosyncline* within which deeper-water phases, including limestones and volcanics, were accumulated to a great thickness with overlapping across the basement on the eastern and perhaps on the western side also.

The Lower Matsap Beds and their Base.—Over great stretches the lowest beds of the group are unfortunately separated by tracts of sand from the nearest outcrops of the older formations and the exact base cannot be seen. East of Olifants Hoek they follow the Upper Griquatown beds without apparent unconformity, but overlap elsewhere. In the Postmasburg area, where a local facies, known as the "*Gamagara Beds*," overlaps on to the Griquatown beds and the Dolomite, a ferruginous Basal Conglomerate may be present, followed by aluminous shales (both replaced locally by manganese ores (p. 531)) and quartzites. Complications have been produced by extensive easterly-directed thrusts. In the high ridges of the eastern foothills of the Langebergen, east of the Andriesfontein beacon, the conglomerates lie some distance above the base of the group and have a hard quartzitic matrix with pebbles of quartz, quartzite, jasper, diabase, and granite.

Near Blaauwkrans, in the north-eastern arm of the Korannaberg, Griquatown beds form the core of two overturned anticlines with limbs dipping westwards and the basal beds of the Matsap carry lumps of magnetite-rock and red jasper, while well-rounded pebbles of quartz and red jasper occur either singly or in layers in the overlying reddish-purple quartzites. At the south end of the Matsap Ridge, however,



View from two miles north of Dedebin in the Koranna Berg, showing ranges of Matsap Quartzites rising out of the plain of red Kalahari sand. Note the " Inselberg " landscape.

PLATE XII

[Face page 206

they lie unconformably on Lower Griquatown beds, but without any coarse phases.

At Zeekoe Baart, in the neighbourhood of the Orange River, where the formation rests mainly upon the Ventersdorp lavas, the conspicuous basal conglomerate, with a red ferruginous quartzitic matrix, shows repeated infolding with the lavas, and is in places so much deformed by pressure that pebbles of hard quartzite and jasper have been stretched or flattened to an extraordinary degree. Sand conceals the junctions with the Kheis System everywhere to the west of the Langebergen, but in the westernmost of the known folds making the Groot Drink ridges on the Orange River the base rests on the Wilgenhout Drift Series. Inclusions of the Kheis quartzites and schists characterise the conglomerates in most places.

By means of these scattered observations it has thus become possible to establish the *unconformable transgression* of the Matsap System across the older formations in a westerly direction. The lower beds near Olifants Hoek include dark greenish-grey shales and dolomitic limestones up to 100 feet thick.

The thickness of this division is estimated to be not less than 3000 feet.

The Middle Matsap Beds.—The distinguishing feature of this division is the presence of a considerable thickness of volcanic rocks, lavas, breccias, and tuffs, which have only been delimited to the east of the Langebergen through a distance of 60 miles; but there is much sand along this horizon and the volcanics may extend much farther both to north and south; to the west it is not unlikely that the group thins out. It attains a thickness of about 2000 feet near Olifants Hoek, where it is best exposed, inclusive of a great deal of quartzites and grits, many of them purplish, others green and white.

The lavas are greenish, much altered, and often amygdaloidal types, for the most part hornblende andesites, accompanied by dark green volcanic breccias and tuffs, also conglomerates containing not only rounded boulders of lava but inclusions from the pre-Matsap strata. Both in this belt and at Dedeben, in the Korannaberg, intrusions of diabase and gabbro occur that may have some connection with the rocks of this division.

The Upper Matsap Beds.—These rocks compose the main range north and south of the valley through the Langebergen occupied by the Matsap River; they also constitute part of the Korannaberg. They are almost entirely purplish quartzites and grits with some gritty sericitic phyllites, but conglomerates and slates are absent. Isolated pebbles of quartz and red jasper occur in the former. Their thickness must be 4000-5000 feet, though impossible to measure exactly because

of the folding which is of an isoclinal nature on the western side of the ranges.

The Matsap beds do not yield so unequally as the Table Mountain Sandstones, so that the fantastically shaped and pitted rocks so characteristic of the Western Province ranges are not found in the northern region. The sand produced under disintegration is furthermore yellow or reddish instead of white or grey.

The Supposed Matsap of the Cape District.—Attention has to be drawn to the strip of "*Klipheuvel Beds*" running from Klipheuvel Station on the railway from Capetown to Malmesbury south-eastwards through Joostenburg with an outlier capping Klapmuts Hill. They rest unconformably on Malmesbury slates or granite, dipping north-eastwards, but are faulted on that side against the slates. Conglomeratic beds full of pebbles of quartz porphyry form the base, the strata being composed mainly of grits, quartzites, and sandstones, bleached to a white or yellow at the surface, but reddish, lilac, and purplish when fresh, together with very subordinate softer beds of similar colouring, in all some thousands of feet in thickness.[1]

The colouring, arenaceous character, and unsheared condition of this thick formation at Klipheuvel serve to distinguish it from the beds at French Hoek (p. 171), while it is certainly older than the Table Mountain Sandstone, which looks down upon it from the lofty Simons Berg.

It is tentatively suggested that, although so far distant from the type area, it may just possibly be the representative of the Matsap beds, with which the lithological resemblances are closest, or even of the still nearer Nieuwerust Series of Van Rhynsdorp.

B. The Waterberg System

Historical. Distribution. Base. Lithology. Volcanicity.

Historical.—The brown, red, and purple arenaceous strata of the Waterberg district were appropriately termed the "Waterberg Sandstone" by Molengraaff[2] in 1899, but their relationship to the older systems remained in doubt until 1904, when several observers announced that they rested *unconformably* upon the Pretoria Series in the south and upon the Old Granite and schists in the north of the Bushveld region.

The same year Mellor[3] announced that at Balmoral, west of

[1] S. H. Haughton, *Union S.A.G.S.*, 1929, Expln. Sheet 247.

[2] G. A. F. Molengraaff, *Rapport o. h. jaar*, 1898, *v. h. Staats geloog, etc.*, Pretoria, 1899.

[3] E. T. Mellor, *T.G.S.S.A.*, 1904, vii, 39; 1905, viii, 38.

Middelburg, these beds had been invaded by the Red Granite and, since they were found elsewhere to be underlain by felsitic lavas and similarly red and purple sediments into which the Red Granite was certainly intrusive, the two-fold grouping into the Upper and Lower Waterberg was adopted, the former of sedimentary, the latter mainly of volcanic origin. At the same time it was recognised that pebbles not only of felsite but of the intrusive Red Granite were common in the conglomerates of the Upper Division, a fact difficult to square with adopted views. In 1922 the members of the Shaler Memorial Expedition not only disproved the intrusive relationship of the Red Granite to the Upper Division, but showed that after the effusion of the felsitic lavas, etc., there must have elapsed a period marked by the injection of the plutonic rocks of the Bushveld, and that subsequent denudation of the so-called Lower Waterberg and of these plutonics had provided much of the material for the Upper Division.

The latter, which was in this way shown to be separated by a highly important time- and erosion-interval from the felsites, etc. (now grouped with the Rooiberg Series), had to be restored to its former rank and re-named the Waterberg System, and corresponds therefore to the division referred to *in literature* up to then as the " Upper Waterberg."

Distribution.[1]—The detached area of the Middelburg district is rather crescent-shaped, some 75 miles in length and bent into a basin with its longer axis running almost east-west (Fig. 27). Dips are generally inwards at low angles except along the northern side, where in several places the strata have been twisted up to high angles. Most of this country stands at an altitude of just over 5000 feet above sea-level.

The main region begins at Warmbaths and extending northwards constitutes the rugged territory known as the Waterberg, the centre of which is called the Palala Plateau and has an average altitude of about 4600 feet. It ends to the north, east, and south in escarpments, the last, 65 miles long, being termed the Sand Riviers Berg ; the highest point is 6841 feet made by the Kransberg north of Rooiberg. Within this rather picturesque

[1] See *Union S.A.G.S. Rep. for* 1903, 7 ; *for* 1904, 37 and 45 ; *for* 1905, 81 ; *for* 1906, 55 ; *for* 1908, 25 ; *for* 1909, 21 and 39. *Ibid.*, Report N.-W. Zoutpansberg Dist., 1908. A. J. C. Molyneux, *Proc. Rhod. Sci. Assoc.*, 1907, vi, 73. G. G. Holmes, *T.G.S.S.A.*, 1904, vii, 51.

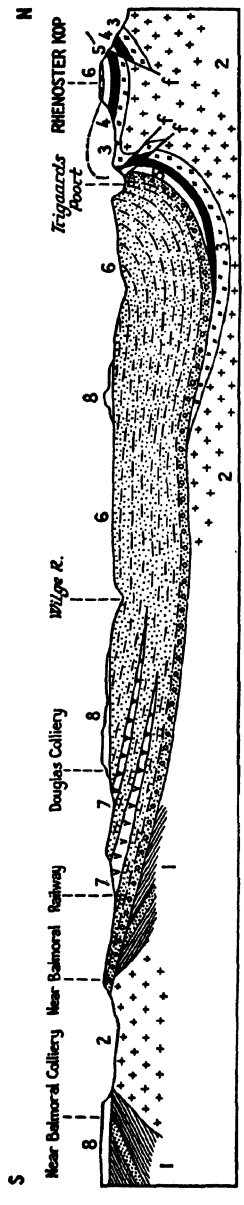


FIG. 33.—Section through the Waterberg Basin near Balmoral, distance 25 miles. 1, Pretoria Beds; 2, Red Granite; 3, 4 and 5, Rooiberg Series (3, Felsites; 4, Shales and Flagstones; 5, Volcanic Agglomerate); 6, Waterberg Beds; 7, Diabase; 8, Karroo Beds.

region in which several perennial rivers take their rise, terraced and table-topped mountains are frequent, such as the imposing Hanglip towering 2300 feet above the Sterk River Valley, or the striking isolated block known as Kranskop rising 750 feet from the sand-covered plain a little to the south-east of Nylstroom.

The eastern boundary of this area runs from Naboomspruit northwards past Zaaiplaats down the Magalakwin River to the prominent mass of the Blaauwberg, 6714 feet, that rises 3000 feet above the granite at its base. A long tongue stretches eastwards to make the Zoutpansberg, which attains its maximum elevation of 5620 feet behind Louis Trichardt and sinks eastwards without reaching the Lebombo Range. Throughout the sand-covered Limpopo Valley post-Karroo faulting directed west-south-west is common and the Waterberg beds of the Zoutpansberg are strongly strike-faulted. Crossing into the Bechuanaland Protectorate the red grits, quartzites, and conglomerates, penetrated by occasional sills of diabase and dipping at low angles, extend in a moderately wide belt up the Notwani River past Mochudi to far beyond Molepolole, passing northwards beneath Karroo strata. Towards the south outliers of Waterberg cap the higher ground between Gaberones and Kanya, form a synclinal basin that is crossed by the railway at Ootsi and give rise to occasional outcrops in the Kalahari, such as Dikgomo Kop at Kooi 50 miles west of Kanya, where the tilted

beds are striking west-south-west towards Tshabong, and about Kakia, along with some limestones, dipping southwards. North of the Crocodile River the Waterberg, resting on the Old Granite, crowns Selika Kop, the Chwapong Range and other hills around Sofala and Palapye Road, and sinks towards the west beneath Karroo beds or sand.

Base. Over the eastern half of the Middelburg *basin* the Waterberg is pseudo-conformable with the sediments formerly ranged with the " Lower Waterberg " but now with the Rooiberg ; nevertheless the presence in the conglomerates of boulders not only of the felsites but of the Red Granite betrays this otherwise unsuspected break. In the western half the Waterberg transgresses across the Felsites to rest on Pretoria beds near Balmoral (Fig. 33), and Red Granite north of the Premier Mine.

Similarly northwards from Warmbaths to the Blaauwberg and Palapye it passes from the Felsites on to the Old Granite, and west of Vliege Poort crosses the upturned edges of the Transvaal and Ventersdorp rocks there and west of Ramoutsa, to lie on the Old Granite at Mochudi.

Lithology.—The most noticeable characteristic of this formation, which is fully 5000 feet in thickness in the Middelburg district and probably much more in the Zoutpansberg, is the dominant brownish, reddish, or purplish colour of the rocks, of which quartzitic sandstones, in thick beds and often pebbly or gritty, compose the bulk, the remainder being conglomerates, flagstones, and shales. The red coloration is doubtless in great part due to the amount of felsitic and other igneous debris present in the original sediments.

Coarse conglomerates, with occasional breccias, mark out the base, though occurring higher up as well, and may range from 100 to 400 feet in thickness, a characteristic being the scantiness of the purplish sandy matrix in which the well-rounded pebbles are set. At Rhenoster Kop north of Balmoral the basal conglomerate carries smoothed boulders of white quartzite up to 4 feet and even 5 feet in diameter set in a greenish matrix. The inclusions consist chiefly of red and white quartzite, together with some of quartz, felsite, norite, diabase, red granite, banded ironstone, and red jasper, and in the Sterk Valley now and again of tourmalinised rocks, which indicate that the mineralisation of the Rooiberg Series had already been effected. In the higher bands, such as

run from Rankin's Pass westwards to beneath the Kransberg, felsite is generally absent, the inclusions being mainly of banded ironstone and quartzite.

Scattered pebbles are found in the grits and sandstones, and the same is the case with the hard greyish quartzites with purplish or reddish patches that are so common in the Zoutpansberg. The centre of the Middelburg basin is filled with soft current-bedded sandstones and grits of a rich purple-red hue that are easily weathered. The subordinate flagstones and hard shales of the formation are deep purple, blue-black, grey, greenish, or striped, sometimes micaceous, and may display fine ripple-marks or sun-cracks; they are better developed in the north-western regions. Thin limestones have been noted at the stad of Palapye. Brick-red sandstones and coarse conglomerates crowded with pebbles of felsite, quartzite, and chert derived from adjacent formations build conspicuous hills along the railway about Ootsi farther to the south, while the hard conglomeratic bands at Molepolole and Kanya are conspicuous because of their brilliant jasper pebbles.

Contemporaneous Volcanicity.—A group of volcanic rocks up to 5000 feet in thickness forms the southern foot-hills of the Zoutpansberg, resting upon the Old Granite, as can be seen in the lower part of Louis Trichardt village, and dipping northwards beneath the Waterberg sandstones. The belt, several miles wide, stretches eastwards past Chibase and down the Pafuri River to Mhingas Location, and westwards to the end of the range at Uitzicht, thinning appreciably. The group includes two constant and one impersistent intercalations of red sandstone, as for example near its top at Trichardt. The rocks have decomposed to form fertile red-brown or chocolate soils, so that this face of the range is better agriculturally than the northern one. They are mostly fine-grained, pale bluish-green lavas with occasional small amygdales and in thin section are found to be fairly fresh, showing augite and plagioclase feldspar; they are andesites and basalts. Although petrographically somewhat different from the Middle Matsap volcanics of the Cape, the parallel is suggestive.

[*Editor's Note.*—F. C. Truter (*T.G.S.S.A.*, 1950, lii, p. 66, has differentiated from the Waterberg succession an unconformably underlying group of sediments, formerly and by the author included in this System, as a separate **Loskop System.**]

C. The Umkondo System

Distribution and Relationships.[1]—This formation, also called the Sabi Series by Mennell and the Spungabera Series by Teale, builds the Melsetter Plateau in Southern Rhodesia from 2500 to 4500 feet above sea-level, terminating in the Spungabera Highlands, a region traversed by precipitous valleys, and overlooking the lowlands of the Buzi River in Portuguese East Africa.

On the east it is normally separated by a north-south fault with downthrow to the west from the quartzites and quartz schists—Frontier Series—making the lofty block of the Chimanimani Mountains, than which it must be younger; on the west it is bounded by the deep south-running trough of the Sabi River, forming a remarkably regular escarpment overlooking a great plain, largely alluvial. Thrown down by warping and faulting the formation stretches along the western side of the Sabi Valley to the Mkwasini River with the strata dipping eastwards.

The structure is that of a shallow syncline which is sinking to the south, with moderate dips inward from both east and west, and which rests unconformably on the granite-schist complex and passes unconformably beneath Karroo beds in the south and south-east. Karroo dolerite is abundant as dykes and sills, some many hundreds of feet thick, in both the sediments and their basement. An interval of 140 miles separates these outcrops from the nearest Waterberg strata of the Zoutpansberg.

Some 400 miles away is found the patch of yellowish to brownish pebbly grits, conglomerates, shales and limestones resting on the tilted Lomagundi beds between Sinoia and Zawi, and beyond that the irregular tract 50 miles across traversed by the Sanyati River in the Sebungwe district, crossed by shallow folds trending south-west. Westwards—more broken—it forms outliers along the Zambezi Valley (passing into Northern Rhodesia), and makes a narrow strip building the Gongoriba Mountain, upfaulted on its north-western side and dipping south-eastwards at 5 to 20 degrees below the Karroo beds of the Sengwe Coalfield. Nearby it composes the Sijalila Hills, a horst 60 miles long by about 5 miles wide trending south-west with scarp facing north-west and with the Karroo beds faulted down on both sides. The

[1] F. P. Mennell, *T.G.S.S.A.*, 1920, xxii, 68; E. O. Teale and R. C. Wilson, *G. J.*, 1915, xlv, 16; E. O. Teale, *ibid.*, 1915, xlvi, 276; *T.G.S.S.A.*, 1924, xxvi, 103; *S. Rhod. G.S.*, 1933, *Geological Map of the country between the Bikita, Zaka, Chipinga and the Lundi River in S. Rhodesia*; A. M. Macgregor, *S. Rhod. G.S.*, 1947, Bull. 38, 45.

quartzites, current-bedded sandstones and grits to a thickness of perhaps 2000 feet—called originally the " Sijarira Beds " by Molyneux [1] and regarded by him as basal Karroo—repose on crystallines (with a basal conglomerate along the Lubu River) and dip gently south-east, though locally contorted. In both of these fault-strips the major dislocations are marked by brecciation and silicification.

The small outliers of red and purplish sandstones and shales with basal conglomerate lying on gneiss at Wankie help to connect with the occurrences in Ngamiland (p. 205).

Lithology.—The basal beds in the Sabi Valley are described by Mennell as bluish-grey limestones several hundred feet in thickness, followed by purplish shales, sandstones, and black, brown, reddish, or grey quartzites associated with some amygdaloids of andesitic type. Such limestones are widely developed not only in the valley of the Sabi, but in that of the Buzi about Chipinga. At the Umkondo Copper Mine casts of crystals of rock-salt are to be found in places on the bedding-planes of some of the shales. Dark shales, some showing rill-marks, seem widespread. Above these lower beds come hard grey sandstones several thousand feet thick.

Mennell's observation that the limestone resting on the Old Granite contained microscopic garnets is explicable as due to intrusive dolerite, for the base of the System was found by the geologists of the Victoria Prospecting Company to be a normal unconformable one, and by Maufe to show a basal arkose in the Umvumvuvu Valley to the north.

The succession given by Teale for the Spungabera Highlands to the east is rather similar, bands of purplish and pinkish shale being in places abundant in the basal portion, and thick-bedded, hard, fine-grained blue-grey sandstones or quartzites higher up, forming imposing cliffs; altered andesitic lavas with vesicles filled with quartz and epidote recall those of the western block. Volcanic rocks of intermediate composition are common to the Spungabera and Zoutpansberg areas, but limestones, which are represented on more than one horizon in the former district, are as yet unknown in the Transvaal.

Economics.—The Umkondo Copper Mine is situated in the downthrown strip a little to the west of the Sabi River. The ore-body is a layer in grey shales overlying quartzite, dotted with nodules of bornite, some of which show crystal edges and appear to be pseudomorphs after pyritic concretions. The resemblance should be noted to the thin " Kupferschiefer " of Mansfeld in Germany, with its occasional small nodules composed of bornite, chalcocite, and chalcopyrite. Mineralisa-

[1] *Q.J.G.S.*, 1903, lix, 266.

tion appears sporadically along the western foot of the main plateau and seems to be connected with post-Karroo intrusion.

D. Tectonics

An outstanding feature is the strong deformation of these strata within certain zones, shown diagrammatically in Fig. 32.

(*a*) In the Gobabis-Ngamiland zone repeated folding is confined to the Ghanzi area, while the Sanyati shows a corresponding flexing with dips up to 45 degrees locally.

(*b*) South of Prieska there appears a sinous zone of compression within the Matsap geosyncline that follows the Doornbergen, Langebergen and Korannabergen, to deviate north-eastwards towards Kanya. The crumpling in mid-section has been intense along north-south axes with isoclines overturned towards the east and with overthrusting and shearing. The western side of the Doornbergen is marked by simple high-angle thrusting. At Zeekoe Baart on the Orange River Ventersdorp, Transvaal and Matsap rocks have been cut up into a complex group of radiating strips.[1]

Detailed mapping east of the Langebergen between Olifants Hoek, Matsap and Postmasburg has disclosed a group of long, low-angle overthrusts within a tract 25 miles wide, whereby successive slices of varied and deformed strata have been pushed over the formations to the east—mainly Dolomite and Griquatown beds—on which they now repose in abnormal positions.[2] This thrusting progressed into higher and more westerly levels, horizontal displacements of up to 9 miles having been estimated. In places, *e.g.* the Wolhaarkop " dome," the rocks forming the sole of the thrust have been gently arched-up under the influence of the over-riding block with the development of intricate structures and minor dislocations, accompanied by brecciation and mylonitisation; indeed, much of the so-called " Blinkklip Breccia " (p. 159) may have been produced in this way. Even in the gently undulating jaspers to the east between Griquatown and Kuruman widespread drag-folding and minor thrusting directed towards the east have been observed.

The production of ores of *Iron* and *Manganese* and seams of *Blue Asbestos* can be connected with this deformation. In the Postmasburg Manganese Fields the structures are particularly complex and extremely important so far as ore genesis is concerned.

[1] *Ann. Rep. G.C. for* 1908, 13-17.
[2] *T.G.S.S.A.*, 1945, xlvii, 217-50.

(*c*) Post-Waterberg movements operated in the central Transvaal along narrow belts with general west-east trend. One of these extends in an arc from Vliege Poort through the Gatberg to Warmbaths in which the several formations have not only been twisted up but sliced by sub-parallel thrust-planes rising to the north. At Zondags Poort [1] the basal beds of the Waterberg together with their Red Granite basement have been overturned towards the north, and the Pretoria beds thrust over them from the south so that the latter actually repose upon the two younger formations, while the Dolomite and Banded Ironstones have been duplicated, producing a double range (Fig. 23).

Its probable extension runs in a narrow zone eastwards from Chunies Poort and finally crosses the Black Reef Series at Mamatswyeri on the Drakensberg with the Dolomite and Banded Ironstones contorted and often overfolded to the north.

(*d*) Similar conditions prevail in and just south of the Stavoren Tinfield and along the northern side of the Middelburg basin, while it is not unlikely that the strong thrusting in the Transvaal System around Pretoria, the fracturing along the Gatsrand between Heidelberg and the West Rand and the remarkable overturning from the west near Potchefstroom may have dated from this time. Conceivably the doming of the Vredefort structure (p. 198) may have been related.

(*e*) *Pattern.* Several distinct compressive phases are clearly indicated for both the Cape and Transvaal, though whether such synchronised is unknown. The peculiarly diverse directions of compression may nevertheless be explained by an anticlockwise twisting of the Earth's crust around a centre in the Langebergen coupled with a powerful push from the west along the 28th parallel. This would form a fine example of a *spiral structure* on a great scale, developed perhaps about early Palæozoic times. Not improbably the post-Nama foldings of the Lüderitz-Van Rhynsdorp belt may have to be ascribed to the above.

E. Correlation of the Waterberg, Matsap, and Umkondo Beds

The question of the relationships of these three formations to one another and also to the other systems is by no means

[1] R. A. Daly and G. A. F. Molengraaff, *Journ. Geol.*, 1924, xxxii, 1.

a simple one, mainly because of the great distances that part the respective areas and of the undesirability of placing too much weight upon their predominantly arenaceous character and purplish or brownish colouring. The strata of the Zoutpansberg tend towards the Umkondo facies through being greyer, more quartzitic, finer-grained and less pebbly than the Waterberg of the Middelburg district. The equivalence of the Umkondo and the Waterberg is strongly suggested. The facies represented between Lake Ngami and Gobabis is very like that of the Matsap. Between Tshabong and Kanya a distance of 90 miles separates the nearest outcrops of Matsap and Waterberg beds, which are not only lithologically similar, but are each striking north-east to south-west.

The Waterberg beds were correlated by Hatch and Corstorphine with the Table Mountain Sandstone of Zululand and Natal, while other geologists have regarded the Matsap beds as the equivalent of the Table Mountain Sandstone of the Cape; in each case a gap of over 200 miles intervenes.

Such a correlation is lithologically, though not tectonically, possible. For the present the data available support the view that *the Waterberg and Matsap beds are of pre-Cape age.* No identifiable fossils have yet been discovered in them and they are manifestly of continental origin. Their age must be either Early Palæozoic or Late Pre-Cambrian.

The facts favouring correlation with the Table Mountain Sandstone are (1) the quartzitic facies of both the Matsap and the Table Mountain Sandstone in the west and south of the Cape; (2) the red, purple, and brown colouring, the general feldspathic nature and the deep-coloured conglomeratic bands of both the Zululand Table Mountain Sandstone and the Waterberg of the Middelburg district; and (3) the presence of pebbles and fragments of brilliant red jasper in the Table Mountain Sandstone in both the eastern and western areas.

The evidence to the contrary is (1) the absence from the Table Mountain Sandstone of any volcanic rocks and of any intrusions, excepting Karroo dolerite; (2) the presence of limestone phases in Matsap and Umkondo; (3) the discovery of pebbles of purplish grit in the glacial band on Table Mountain; (4) the purplish quartzitic pre-Cape Klipheuvel beds near Cape Town; and (5) the intense local folding and subsequent erosion of both the Matsap and Waterberg beds that must have been performed during the relatively short period denoted by the deposition of the few thousands of feet of Bokkeveld and Witteberg beds, which is rather improbable.

The possible equivalence of the Matsap with part or even the whole of the Nama System has not a little to commend it, but no exposures have been found bridging the gap near Upington. On the contrary a possibly younger age for the Nama System should not be overlooked.

F. The Post-Waterberg Intrusions and the Alkaline Rocks

Intrusions, chiefly of diabase, in the form of sheets and sometimes of dykes have invaded the Waterberg System, though on a limited scale, but may be wider spread than is currently believed, since in some places they have not been discriminated from the earlier injections belonging to the Bushveld Complex. In addition they have their representatives—diabase and gabbro—in the Cape Province, penetrating the Matsap System in the Langeberg and Korannaberg.

To this period of igneous activity belong the numerous occurrences of the alkaline rocks in the Transvaal that have already made that territory celebrated in the world of petrology. A younger age than the post-Waterberg diabase has been established in one instance, although it is probable that the time-interval was only a small one; indeed, the phenomena are such as to suggest that the alkaline rocks arose indirectly from this generally basic magma of post-Waterberg age.

(1) **The Non-Alkaline Rocks.**—Sills of a medium to coarse-grained diabase—sometimes containing patches of micropegmatite—like that of the Bushveld Complex, but with the light brownish augite much fresher and not usually altered to uralite, are found here and there in the Waterberg beds not only within the Transvaal but in the Bechuanaland Protectorate as well, as at Molepolole and Shoshong, and are specially developed to the north of the town of Middelburg and along the Matlabas Valley and Sterk Valley to the north-west.

On the farm Rooiwal at the head of the latter the greenish diabase of a sheet passes upwards through a few feet of transitional rock into a red granophyre showing a little green hornblende and porphyritic orthoclases surrounded by fine micropegmatite. The occurrence is regarded by Mellor as a case of differentiation within the basic body, but by McDonald as a composite sill. A similar example can be cited from the farm Haarlem Oost on the Matlabas River, where the red granophyre

contains many pebbles derived from the Waterberg sandstones, a phenomenon that has been observed at Rooiwal also.

The dyke-like intrusions will be referred to below.

(2) **The Alkaline Rocks.**—Various kinds of alkali syenites and their hypabyssal and effusive equivalents—including very rare types indeed—have been recorded from spots within or just outside the present limits of the Bushveld basin. Their study by Brouwer and Shand has furnished information of no small value from the standpoint of petrogenesis. The following account, based on their geographical distribution, is purposely brief; for details regarding these peculiar igneous rocks reference must be made to the original descriptions.[1]

(a) *The Pilandsberg or Pilansberg.*[2]—This unique mass of broken country to the north of Rustenburg, rising abruptly from 1000 to 2000 feet above a plain of Norite and Red Granite, is wonderfully regular in its outline, almost circular with a diameter of 17 miles. The rocks forming it belong to two main groups, each with its plutonic and effusive representatives, namely (1) the *alkali syenites* and *trachytes*, and (2) the *nepheline syenites* (*foyaites*) and *phonolites* together with breccias and tuffs.[3]

The geological map (Sheet No. 12) brings out the roughly concentric distribution of the various extrusive and intrusive types. Humphrey asserted that the lavas have a general outward dip and that the area marks the site of a stupendous volcanic cone that formerly rose high in the air. Shand's more detailed work and mapping [4] have indicated that dips, where measurable, are normally inwards at about 30 degrees, that the phenomena suggest the building up of several cones of lavas and tuffs with the repeated intrusion, between the erupted materials and their floor, of alkalic and non-alkalic magma in the form of sheets, accompanied by sagging in the centre. Stripped of its covering of lavas there appear five plutonic rings with red foyaite at the

[1] H. A. Brouwer, *Oorsprong en Samenstelling der Transvaalschen Nepheliene-Syenieten*, 1910; "On the Geology of the Alkali Rocks in the Transvaal," *Journ. Geol.*, 1917, xxv, 741. S. J. Shand, "The Nepheline Rocks of Sekukuniland," *T.G.S.S.A.*, 1922, xxiv, 111; "The Alkaline Rocks of the Franspoort Line, Pretoria District," *ibid.*, 1923, xxv, 81; "The Problem of the Alkaline Rocks," *P.G.S.S.A.*, 1922, xxv, p. xix; *Eruptive Rocks*, 1943, ch. xviii.

[2] See Fig. 27, on which the principal occurrences are indicated.

[3] W. A. Humphrey, *Union S.A.G.S., Rep. for* 1912, 77; *T.G.S.S.A.*, 1912, xv, 100.

[4] S. J. Shand, *T.G.S.S.A.*, 1929, xxxi, 97.

centre surrounded in turn by white foyaite, green foyaite, white foyaite and red syenite. The relations between the various types are naturally complicated.

The Complex is definitely of pre-Karroo and apparently of post-Waterberg age.

On the outer margin between Rhenosterspruit and Sauls Poort a most remarkable series of coarse volcanic breccias can be studied containing boulders of Red Granite, red syenite and foyaite cemented by a matrix carrying ægirine and riebeckite with fluorspar. Inside, on and around Kaffirskraal, are several large areas of noritic rocks in abnormal position, which may represent shattered and upraised portions of the " floor," while on Rhenosterspruit large inclusions of red sandstone and conglomerate embedded in breccia strongly resemble Waterberg rocks. The red syenite has proved in part to be older than the foyaite, while an arc-like dyke of tinguaite (composed of feldspar, nepheline, and ægirine in a fine-grained base) cuts through the Complex on the south-east, forming the crest in that quarter.

The red syenite calls for no comment, but the foyaites are whitish, greenish, and reddish rocks, occasionally somewhat foliated, with tabular crystals of soda-potash feldspar, ægirine in long crystals, nepheline, sphene and frequently sodalite, eucolite, eudialyte, cancrinite and other rare minerals (see Analysis No. 36). The lavas include fine-grained and highly porphyritic types, red felsitic rocks, trachytes and tuffs; elsewhere are phonolites with nepheline, orthoclase feldspar and ægirine, sometimes carrying sodalite, cancrinite, etc.

In the south-east the outer ring of red syenite is cut by an intrusion of nepheline syenite belonging to the north-west trending dyke-system of the Bushveld; other members are found on the north-western edge of the Pilansberg as well. On Vaalboslaagte and Palmietfontein much younger kimberlite pipes pierce the Complex and contain many inclusions therefrom.

This great vent is located upon the axis of the Lopolith close to the point where ridging-up has taken place, and also where the synclinal, sheet-like mass of the Red Granite of the main basin comes to an end.

(b) *Sekukuniland.*—The plug-like body (Fig. 27, 6) on the farm Spitzkop (No. 463) is several miles in diameter and truly remarkable for, while piercing the Red Granite, it includes a foreign mass of limestone forming a core about half a square mile in area that must have been carried up by the magma from the Dolomite, which cannot be less than several miles in depth at this point (Fig. 34, B).[1] The rock is mostly foyaite, composed

[1] S. J. Shand, "*Eruptive Rocks*, 1943, Fig. 45.

of orthoclase, albite, nepheline, and acmite, and becomes schistose at the periphery of the plug.

(c) *The Franspoort "Line."*—Shand has given this name to the four plugs (Fig. 27, 2-5)—mainly nepheline-syenites—with accompanying dykes that are located on a line extending from near Hatherly east of Pretoria in a north-north-westerly direction; to the west is the Saltpan wherefrom boulders of allied rocks have been gathered. To them can be added the breccias on Roodeplaat, Kameeldrift and Derdepoort (Fig. 27, 7) nearby. The last two have Red Granite inclusions, the last-named piercing the Magalies-

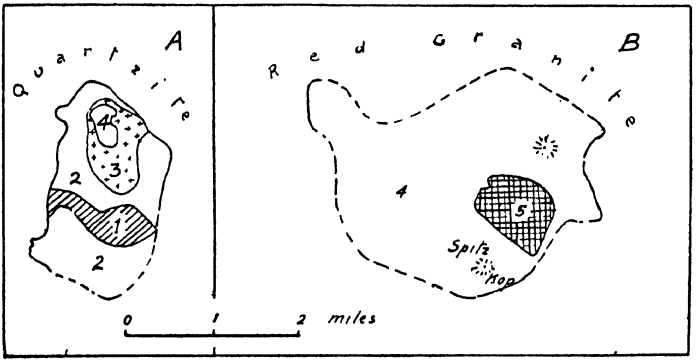


FIG. 34.—Alkali-syenite plugs; (A) Leeuwfontein (Pretoria), (B) Spitzkop (Sekukuniland). 1, Soda trachyte; 2, White Syenite; 3, Red Syenite; 4, Foyaite; 5, Limestone. (*After* Shand.)

berg Quartzites and containing much crystalline limestone derived presumably from the underlying Dolomite.[1]

(i) Most illuminating is the as yet undescribed elongated eruptive body up to nearly a mile wide on Zeekoegat and Roodeplaat close to Leeuwfontein, sectioned by the Elands River (Fig. 27, 8). Here, at the top of the Magaliesberg group a block, over one and a half miles long, of Waterberg beds—mainly conglomerates with pebbles of felsite—has subsided with northward tilting into this mass of brick-red syenitic rocks which riddle the block. *The post-Waterberg age of these alkaline rocks is thereby established.* Along its northern side the Rooiberg Felsites have become entangled and so altered that boundaries are in many places indefinite. Explosion breccias full of inclusions

[1] F. A. Venter, *T.G.S.S.A.*, 1933, xxxvi, 41.

of Pretoria, Rooiberg and Waterberg rocks are finely developed, well exposed in the Elands River gorge. On the southern side of the belt foyaites occur; along its northern, massive fine-grained syenites are found with monchiquites locally.

(ii) The Leeuwfontein and Leeuwkraal occurrences are volcanic pipes from which soda trachytes and phonolites (Analysis No. 37) were emitted. The first named, shown in Fig. 34, A, is 2½ miles long by half that across, and has three confocal plugs injected in the following order apparently: white syenite, red syenite (Analysis No. 34), and nepheline syenite (foyaite) (Analysis No. 35), while the dykes include a varied assemblage. A sheet of nepheline syenite-porphyry (Analysis No. 38) is exposed on the ridge making the eastern boundary of Paardefontein (No. 338), six miles to the east of the Walmansthal plug and is perhaps connected with the Franspoort Line.

(d) *The Vredefort Area.*[1]—Three bosses of alkali granite are known, two of them each 2 miles in length, on the Vaal River below Parys (Fig. 12) piercing the Witwatersrand beds, and one nearly 4 miles long on Rietfontein more towards the north penetrating the Dolomite, which has been metamorphosed thereby. The first two are granites containing the soda-amphibole arfedsonite, and are hence uncommon rocks (Analysis No. 33); the third is a closely-related soda granite. Each of the bosses is accompanied and cut through by one or more dykes of nepheline syenite, the important lengthy intrusion crossing the Rietfontein mass being a pink porphyritic rock.

(e) *The Bushveld Dyke Swarm.*—An important series of dykes, basic to intermediate in composition, traverses the Bushveld, in which a width of from 20 to 250 feet is common, trending west of north (Fig. 27). Being rather crowded together on the opposite sides of the Pilansberg, and being related petrologically to the rocks of that volcanic centre, they have generally come to be regarded as a system connected with that vent and have indeed occasionally been termed the " Pilansberg Dykes." Conspicuously they fan out in opposite directions from that centre—to the south in the area between Potchefstroom and Springs, reaching to the Vaal: to the north to the Bechuanaland border—an extreme

[1] G. A. F. Molengraaff and A. L. Hall, *Kon. Akad. Weten. Amsterdam, Proc.*, 1924, xxvii, 465; L. T. Nel, *Union S.A.G.S.*, Expln. Geol. Map, Vredefort, 1927, 68.

distance of 170 miles. Some of them follow in places post-Red Granite faults. Although often covered by soil for long distances, their direction and continuity have been established by magnetometric surveys, their positive magnetisation usually enabling them to be distinguished from other dykes.[1] Possible offshoots from them may be certain syenitic or dioritic sills (Analysis No. 39) mainly confined to the Dolomite, for instance on the East Rand or immediately to the south of Pretoria. The dykes cut all formations up to the Red Granite as well as post-Bushveld fault-lines—*e.g.* at Pretoria—though a post-Waterberg but pre-Karroo age can be inferred from other evidence. A dyke, however, of allied rock (camptonite) belonging to the alkaline clan cuts the Waterberg beds near Warmbaths.

A conspicuous feature about them is their frequent *composite character*—the central part being *more acid*—a peculiarity that applies to both basic and intermediate types ; the variation may be quite considerable too. They can be classed as (i) diorites, diabases and gabbros, (ii) monzonites, and (iii) syenites and nepheline syenites.

(i) The structure may be gabbroidal as in the Pinedene-Fountains dyke near Pretoria—with plagioclase, diallage, hornblende, etc., and some interstitial micropegmatite—or it may be ophitic, sometimes with large greenish-yellow plagioclase crystals, as in that at Wolhuter's Kop station. At the margins the rock becomes darker and finer-grained. Augite diorites are common on and to the south of the Rand and again to the north-west of the Pilansberg.

(ii) In the monzonites (augite syenites) ophitic diabase forms the marginal portions with black selvedges, while the interior, roughly from one-third to two-thirds of the dyke, consists of a dark-reddish mottled augite syenite with abundant apatite and some micropegmatite ; a dark " hybrid " zone intervenes between the two types showing both the ophitic and granophyric structures, while small acid veins may occasionally be present.[2]

(iii) Certain of the red syenitic rocks seem closely allied to the monzonites, while a few are nepheline syenites, some with large porphyritic orthoclase feldspars, as for example those cutting the Magaliesberg Range at Breedts Nek south-east of Rustenburg and

[1] See H. Gelletich, *Beitr. ang. Geophysik*, 1937, Bd. 4, 337.

[2] This type was first described by D. P. McDonald (*T.G.S.S.A.*, 1912, xv, 140) from an intrusion in the Klip River Valley south of Johannesburg, but the suite in that area has since been examined by Mr. J. L. Andrew, who has kindly allowed me to utilise information as yet unpublished.

traceable with short breaks to near Parys. Where one passes Bank Station west of Randfontein it is a handsome pink rock with an abundance of inclusions of a darker variety of syenite and can be called a foyaite-porphyry. These alkaline types may also exhibit margins of a grey rock into which the red syenite passes by degrees. Enlightening is a case just to the south of Wolhuters Kop station on the Rustenburg railway in which a dyke very similar to that at Bank cuts obliquely through a porphyritic diabase intrusion, each having more basic margins.

The phenomena strongly suggests that the majority of the dykes are really composite : that the fissure was first filled with basic magma and that very shortly afterwards a more acid and alkaline fraction was introduced into the still-unconsolidated interior. A parallel can be found in certain of the sheets intrusive in the Waterberg beds, mentioned earlier. In the dykes the earlier cooled portions are the most basic, the nepheline syenites appearing to be the *latest* product of the differentiation.

Origin of the Alkaline Rocks.—In view of the opinion of Daly [1] that this group of rocks has arisen primarily through the " desilication " of magmas of normal composition by contact with carbonate rocks, it is indeed striking to find that in almost every instance the intrusions in question, where now seen, have penetrated in depth the dolomitic limestones of the Transvaal or Nama Systems. In the case of the Sekukuniland body, Shand has shown that the intrusion around the great limestone " inclusion " becomes richer in lime and magnesia, but lower in silica and iron, passing into a type without feldspar consisting essentially of nepheline and ægirine with some sphene and cancrinite, known as ijolite. In the Leeuwfontein plug the later phases of intrusion are marked by a decrease in the silica and iron content and increase in soda and alumina. The limestone in the Derdepoort body has the same composition as the Dolomite. The Bushveld Dyke System too displays very clearly the progress from normal basic to alkaline intermediate types with time. Kaiser has pointed out that the phenomena near Lüderitz (p. 410) imply that the foyaite bodies did not push aside the country rocks, but melted their way upwards through the supposed Nama beds, and has remarked that the majority of the observations rather favour Daly's views. The vents south of Windhoek must penetrate beds of limestone.

Shand [2] has brought out evidence to show that the " over-saturated " alkaline rocks such as the soda granites may have been developed in the normal course of crystallisation within a normal non-alkaline magma, while the " under-saturated " kinds on the other

[1] R. A. Daly, *Igneous Rocks and the Depths of the Earth*, 1933, ch. xxi.
[2] S. J. Shand, *P.G.S.S.A.*, 1922, xxv, p. xix.

hand may have arisen through the reaction of a non-alkaline magma on limestone. Most of the South African occurrences comply with Daly's hypothesis, while the alkaline granites on the Vaal River, which are difficult to interpret in this way, can be accounted for under the first process. The evidence to hand is in favour of this parent magma having been basic to start with, no doubt a re-fusion of material at the base of the Bushveld Lopolith. The close association of alkaline rocks with normal basic types has frequently been observed in other parts of the world.

CHAPTER X

THE NAMA SYSTEM

Historical. Stratigraphical. Northern Region. Central Region. Southern Region. Fossils. Tectonics.

Historical.—The nearly horizontal strata of the interior plateau of South-West Africa were called by Schenck the "*Namaformation*" in 1885, though in 1893 he speaks only of the "Sediments of the Huib and Han-ami Plateaux"; at that time they were indeed regarded as the equivalent of the Cape System and were occasionally so styled. In 1910 Schenck revived the term Namaformation—which included the Otavi Dolomite—and this came to be fully accepted by the other German geologists. Its continuity with the strata of Gordonia, called the "Zwartmodder Beds" by Rogers in 1907, was later established. Subsequently the close and detailed resemblance—supported by intervening outliers—between the sequences in Van Rhynsdorp and the type Nama of northern Namaqualand induced Rogers in 1912[1] to ascribe the strata around Nieuwerust (Nuwerus), at least several thousand feet thick, to that System, a conclusion that would seem well founded. Since then opinion has nevertheless wavered in regard to the rather similar beds in the Olifants Valley commonly deemed to be of Malmesbury age, but only recently were these two folded and faulted formations discriminated in that area. Southwards both pass beneath the nearly horizontal Table Mountain Sandstone.

As thus defined the Nama beds occupy a stretch of 1200 miles within the western part of South Africa, which can conveniently be divided into three regions: the Northern, Central, and Southern (Fig. 32).

Stratigraphical.—Considering their wide distribution, the descriptions given by Hermann, Kuntz, Range, Rimann, Kaiser, Beetz, Stahl, Rogers, and Brink for the sequences in the several areas are in fair accord, showing a strong basal unconformity, a three-fold succession, and a marked absence of contemporaneous volcanic rocks.

[1] *T.G.S.S.A.*, 1912, xv, 31.

Northern.—(1) Basal or Nosib Quartzites and Conglomerates, (2) Otavi Dolomite, (3) Quartzite (the so-called "Waterberg Beds" were discovered by Reuning to be of Karroo age (p. 331)).

Central.—(1) Kuibis Quartzites, (2) Schwarzkalk Beds, (3) Fish River Beds. The Zwartmodder Beds of Gordonia are a facies.

Southern.—(1) Nieuwerust (Nuwerus) Quartzites (with an important wedge-like calcareous group beneath them in the south), (2) Schwarzkalk Beds, (3) Higher beds (corresponding roughly to the "Ibiquas Beds" of Rogers).

A. Northern Region

The OTAVI SYSTEM[1] forms a curving belt from the Grootfontein district westwards into the Kaokoveld and northwards to the Rua Cana Falls on the Cunene River with an important patch crossing that river farther down, as well as extensive terrains more to the north in Angola. The strata, 4000 feet thick in the west and over 10,000 feet in the east, are moderately to steeply folded along axes trending north of east in the east and east of north in the west. They produce barren and rugged land in the Kaokoveld but less broken and well-timbered country in the districts of Outjo, Namutoni, Otavi, and Grootfontein. That eastern region has a moderate rainfall, but is typical "*karst*" country, watercourses being rare and caves and sink-holes frequent. The most remarkable of the latter is the Otjikoto Lake a dozen miles from Tsumeb, which covers about ten acres, with walls descending sheer into water having a depth of about 600 feet. Quite a number of important springs issue from the dolomite, even in the dry north-western section. On the northern side the rocks sink beneath the sand and surface limestone of the Kalahari plain.

(a) *The Basal or Nosib Series* consists of coarse reddish conglomerates, grits, arkoses, and sandstones, often false-bedded, and up to 1200 feet thick, though variable and thinning out

[1] P. Hermann, 1908, *Monatsber. D. Geol. Ges.*, 60, 259; J. Kuntz and C. Krause, 1913, *Zeit. Prakt. Geol.*, 21, 64 (map); H. Schneiderhöhn, 1921, *Abh. Senckenbergischen Natur. Gesell.*, Bd. xxxvii, 3, 220 (map); 1929, *Zeits. Prakt. Geol.*, 37, 90; A. Stahl, 1930, *Neu. Jahr. f. Min.*, B-Bd. 64, Abt. B, 165; C. M. Schwellnus, 1944, *Union S.A.G.S.*, Mem. 39, 129.

in places, so that the platy dolomite comes to rest directly on crystallines.

Such beds build the Hundskopf Mountains east of Sesfontein in the Kaokoveld. On the Cunene red feldspathic grits and conglomerates overlying schists hem in the river at the great Rua Cana Falls with a drop of 406 feet, and form the Kavale Rapids higher up. Downstream of the latter a presumed glacial conglomerate, full of gneiss blocks and underlain by dark limestones and shales intervenes between the red sandstones and the basement gneiss.[1] On the right side of the Cunene, at the Tjamalindi Mountain 60 miles from the sea, glacials overlie, probably with disconformity, reddish sediments and are overlain by quartzites, shales, and limestones ascribed to the Nama System, while those several horizons are represented farther to the north in the Chella Plateau in Angola.[2]

(b) *The Otavi Dolomite* is estimated at from 7000 to 10,000 feet thick, though not easy to measure in the flatter country, where it is much concealed by secondary limestone. It is probably the thickest formation of its kind in the world.

Generally light grey, it is divisible into several groups—massive dolomite at the base, thin shales, platy limestone and massive dolomite, which becomes darker towards the top through the presence of black dolomite, fœtid limestone, black chert, and oölitic limestone. In the Kaokoveld it contains a thick sandstone member fairly low down (Stahl).

At the Maieberg east of Otavi, at about 1000 feet up, a band of *tillite* up to 150 feet thick has been discovered,[3] with fine-grained calcareous blue-grey matrix carrying inclusions mainly of quartzite and dolomite with some of granite up to 3 feet long showing facetting and striation.

This formation is of great economic importance for the Copper-lead deposits of Otavi and Tsumeb (p. 510), while valuable ores of Vanadium are obtained at a number of points nearby (p. 545). In the Kaokoveld immense quantities of Iron-ores are said to occur.

(c) *The Quartzite Series*, at the top, is formed by over 1000 feet of indurated arkoses and grits that were formerly mistaken for an intrusive mass—the so-called "aplite."

[*Editor's Note.*—Although the author has here correlated the Otavi System with the Nama System, there exists a body of opinion

[1] M. S. Taljaard, *Ann. Univ. Stellenbosch*, 1938, xvi. sect. A, 21.
[2] P. F. W. Beetz, 1934, *T.G.S.S.A.*, xxxvi, 137.
[3] H. D. le Roex, 1942, *T.G.S.S.A.*, xliv, 207.

in favour of considering it as the South-West African equivalent of the Transvaal System. On the other hand, F. C. Truter (*T.G.S.S.A.*, 1949, lii, p. lxiii) appears to accept a statement by H. Martin that the Otavi System passes laterally into the Damara System and that the two are of the same age.]

B. Central Region [1]

Nama beds appear south-east of Windhoek and run westwards south of Rehoboth and thence in a broad belt almost midway down that Territory, overlain east of the Fish River by Karroo beds, and giving off one arm to the sea south of Lüderitz —in which is situated the Witputs (Witpütz) " trough-valley "— and the other inland to Rietfontein village and Upington. Throughout, the formation commonly ends in the west in scarps facing seawards and passes eastwards beneath the sand and tufa of the Kalahari. At Viools Drift on the Orange River a shallow syncline passes into Namaqualand, the continuation of which, faulted against crystalline rocks on its eastern side, trends south past Springbok. After a gap outliers are found about Garies that form a link with the wide development in Van Rhynsdorp, and possibly the " Klipheuvel beds " near Cape Town.

Striking are the general absence of intrusive rocks and the relatively undisturbed attitude of the beds, wherefore the scarp and the plateau dominate, though block-faulting is fairly common —in part of post-Karroo age. However, along the south side of the Windhoek Highlands there is considerable folding, in places isoclinally with strong dislocation, in the " Namib Fault Zone " that trends northeast-southwest, under pressure from the northwest (Martin and Korn).

(a) *The Kuibis Beds.* Through an immense stretch these rest with *strong unconformity on an evenly planed-down surface of older rocks,* for the most part crystallines. This is finely displayed on the western face of the Naukluft Mountains or the furrowed scarp of the Little Karas Mountains (Fig. 35). However, both to north and south of Kuibis ridges or pinnacles of the gneiss floor project here and there in remarkable fashion into and even through

[1] A. Schenck, 1910 (Hans Meyer's *Das Deutsche Kolonialreich*) ; P. Range, 1912, *Beitr. Geol. Erforsch. Deutsch. Schutzgeb.*, Heft 2 ; A. W. Rogers, 1912, *T.G.S.S.A.*, xv, 31 ; P. A. Wagner, *Union S.A.G.S.*, 1916, Mem. 7.

this group. The same is the case between Karasburg and Upington, as finely seen near Nakob and Langklip stations (Fig. 36).

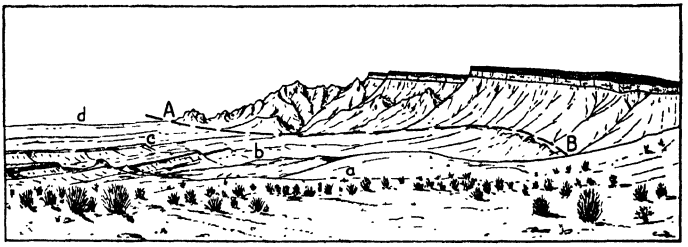


FIG. 35.—The Little Karas Mountains viewed from a point south of Holoog. The Nama Quartzites (*a*) resting on gneiss are thrown down along the fault AB into the valley of the Kab River; (*b*) Schwarzkalk, (*c*) Schwarzrand, (*d*) Fish River Beds with overlying patches of Dwyka Tillite. In foreground are clumps of Melkbos (Euphorbia).

Around such cores the beds dip away at angles but slightly less than the inclinations of the rock-floor, flattening out farther away, boreholes proving an overlapping against such projections of the floor. The apparent tilting of the lower layers has resulted from shrinkage during consolidation, the higher strata stretching out undisturbed.

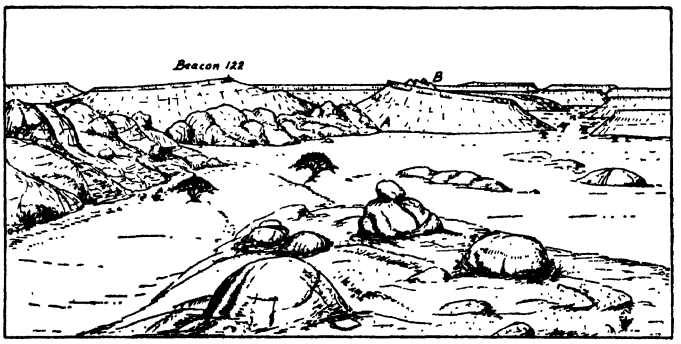


FIG. 36.—View on boundary between the Cape and South-West Africa a couple of miles south of Nakob. Red porphyritic gneiss in foreground, overlain by soft flagstones and hard quartzites. Observe the unevenness of the floor at A and the pinnacle of gneiss jutting out at the top of the quartzite-capped ridge at B. The flats are largely sand-covered.

The hardness of the basal beds and their little disturbed attitude are responsible for a terraced topography, as seen in the bare, ragged escarpments of the Han-ami and Huib plateaux or

Western scarp of Neint Nababeep on Orange River, Namaqualand. Nieuwerust (Kuibis) Quartzites in foreground followed by dark shales and limestone of the Schwarzkalk Series.

PLATE XIII

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in sharp-edged cappings, such as the Gansberg that rises to 7662 feet west of Rehoboth.

This group is up to 500 feet thick at Nieuwerust, 30 feet to the south-east of Garies, 300-400 feet on the Orange River, 500-600 feet near Kuibis, but swells greatly in the Rehoboth district. It is commonly divisible into :—(i) A variable Lower part, nearly always feldspathic and conglomeratic, carrying locally large boulders of granite, gneiss, quartz porphyry, quartzite, jasper, etc., in places representing scree-deposits. On the Orange River, just above the junction of the Fish River, is a local downward continuation of the Kuibis beds consisting of quartzites, conglomerates, limestones, and a 50-foot *tillite*, called the " Nabas Beds." [1] (ii) An Upper part, the " Kuibis Quartzites " *sensu stricto*, more siliceous and often highly current-bedded, weathering buff or brown, though typically bluish when fresh. South-east of Windhoek the group is redder and perhaps of terrestrial origin. Noteworthy is the discovery between the Great and Little Karas Mountains of glaciated surfaces—showing general north-south directions—forming the top of the Kuibis quartzite, overlain by a *tillite* and that by the Schwarzkalk.[2]

(b) *The Schwarzkalk Beds.* The quartzites grade through some soft white, pink or grey shales into an important group of dark blue-black limestones, which weather grey, brown or black—occasionally red or yellow—and occur in thick massive beds or thin layers alternating with dark shales and flagstones, and passing upwards by reduction in thickness or number of the individual limestone bands into a succession of greenish and dark shales and soft greenish and greyish sandstones, formerly known as the " Schwarzrand Beds." The magnesia content of the calcareous strata is generally low and the rocks are mostly *limestones*, while chert is absent or in thin bands only, thus differing from their dolomitic equivalent in the Northern Region. The dark colour is due to organic matter, while the associated shales are pyritic and occasionally bituminous, wherefore the name " Schwarzkalk " is well deserved.

To the north of Nieuwerust 3000 feet have been measured (of which 700 feet are limestones and dolomites) and about 2000 feet in the escarpment of the Neint Nababeep Plateau (Plate XIII), with the same amount of calcareous beds. At Holoog south of Seeheim

[1] J. de Villiers, *T.G.S.S.A.*, 1946, xlviii, 135.
[2] C. M. Schwellnus, *T.G.S.S.A.*, 1942, xliv, 19.

the calcareous member is much split up with shaly layers, while east of Karasburg the limestones disappear. The calcareous zone is, however, traceable northwards through Bethanie into the Naukluft Mountains and north-eastwards to Gobabis, where Passarge recorded them as about 350 feet thick, and again far to the east projecting through the sand of the Kalahari along the south side of Lake Ngami with a thickness of 75 to 170 feet, resting on a group of sandstones and greywackés, though these eastern strata may be of Matsap age.

The rocks in these two areas consist of grey, yellow, red, and violet crystalline limestones alternating with calcareous shales and sandstones. At Lake Ngami the strata are dipping south-eastwards at moderate angles, but are considerably broken by fractures trending north-east, and invaded by much dolerite, probably of Karroo age.

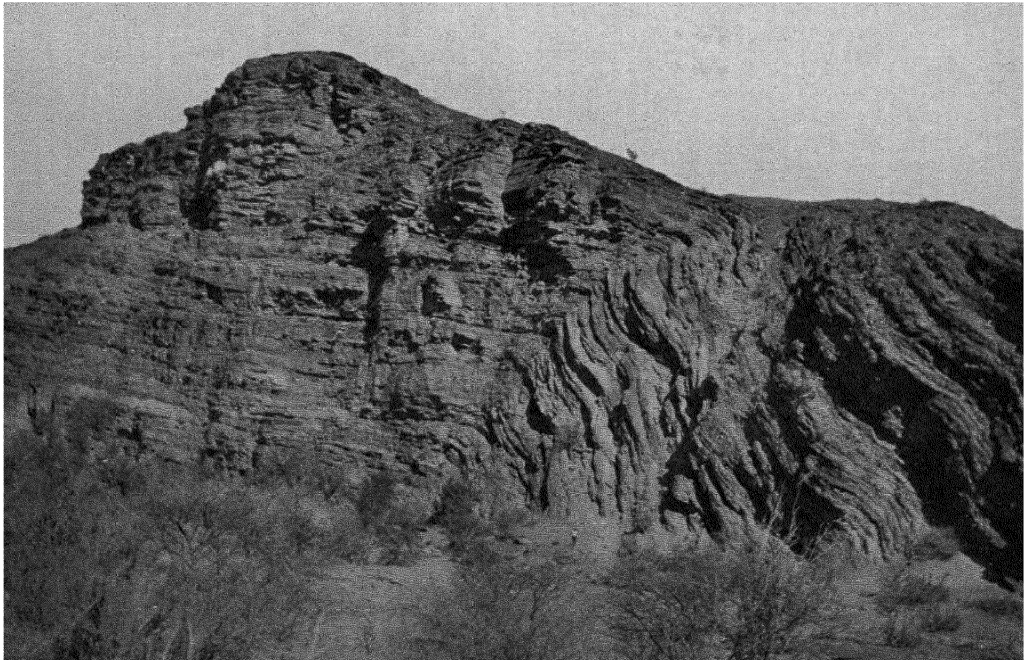
(c) *The Fish River Beds.* Dislocated by the great fractures that border the western sides of both the Great and Little Karas Mountains, and traversed by occasional sharp monoclinal folds, also with north-north-easterly trend (Plate XIV), these beds spread over the south-eastern corner of the Territory, from Hasuur to the Orange River Valley, concealed in places by tufa or red dunes. Their thickness here is fully 1000 feet, but may well exceed that figure in the north-east.

As typically developed in the Fish River Valley, where they crown the Schwarzrand, the beds consist of soft feldspathic sandstones, frequently micaceous, of pink, red, or purplish colour—sometimes striped—current-bedded, ripple-marked or with clay-pellets, sometimes massive, sometimes laminated, along with yellowish, bluish, green, brown, and maroon micaceous shales and flagstones. Seen in the cliff-sections of this arid region these rocks are very striking in their depth and variety of colouring. Hard, black magnetic layers, very rich in detrital iron ores, sometimes in garnet and other heavy minerals, are common in places, being evidently natural concentrates like the " black sand " deposits in different parts of the world.

Traced westwards, Martin has found as their folded equivalents in the Naukluft Mountains a dolomite-shale facies 2-3000 feet thick with a tillite towards the top.

In the south-east, extending into Gordonia, are the " Zwartmodder Beds " of Rogers,[1] largely of the Fish River type with no limestones,

[1] *Ann. Rep. G.C. for* 1907, 43.



Monoclinal fold in the Fish River Sandstones and Shales, Gamharus on the Lion River, south of Keetmanshoop.

[Face page 232

but thin basal quartzites. Conspicuous in this facies are the thin grey quartzite layers sharply differentiated from the thicker bodies of red, purple, and green shale, while ripple-marks, clay-pellets, and calcareous lumps denote shallow-water deposition, though probably remote from land. In the Gobabis area, however, much of the succession is reddish or greenish argillaceous and red quartzitic sandstones with occasional red shales, continued eastwards in the " Chanse Greywackés " of Passarge (p. 205), which, while resembling the Fish River beds, have also a likeness to the Matsap formation. On the other hand, two distinct systems may be involved in that quarter.

C. Southern Region [1]

South-east of Garies the Nama beds spread over the plain of the Knersvlakte (Kneghtsvlakte) and lower Olifants Valley to pass beneath Dwyka conglomerate in the east and Table Mountain sandstone in the south. Lamont has discovered that the main area becomes broken up towards the Olifants, where strata showing a higher grade of metamorphism and including shales and dolomite, and of unknown age (Hilda Series ?) predominate, against which at Moedverloor, north of Holrivier Station, the Nama beds have been faulted. The Klipheuvel beds are described on p. 208.

North of Nuwerus the Nama formation rests on the pink gneiss and is gently flexed, though repeatedly sliced by roughly north-south faults having downthrows mostly inland, the " Nieuwerust " quartzites—corresponding to the Kuibis group—dipping regularly below the Schwarzkalk shales, limestones, and higher beds, the assemblage becoming openly folded along north-west-southeast axes in the southerly direction, but flattening out eastwards.

Not only do the quartzites thicken southwards, but south of Mosterts Kop a new wedge-like group of shales and limestones makes its entry below, but conformable to, the Nieuwerust quartzites, one that becomes more important towards the south (Lamont), introducing incidentally a third calcareous group into this complex, sand-covered region.

(*a*) The Basal Limestone group is well exposed along the Zout River, up to 1000 feet thick, and along the Widouws River to 2-3000 feet, at Aties, and in patches along the Olifants below Vredendal, with

[1] A. W. Rogers, *T.G.S.S.A.*, 1912, xv, 31; W. C. Brink, *Ann. Univ. Stellenbosch*, 1950, xxvi, 97; G. T. Lamont (Univ. Cape Town—unpublished thesis, 1947).

the suggestion in two localities of *unconformable superposition* on much older phyllites. It includes limestones and "marbles" of various colours—some containing sulphuretted hydrogen—and greenish shales. The passage into the group above is marked by alternating limestone and quartzite. (*b*) The Quartzites—thin in the north and increasing to about 1300 feet in the south—give rise to ridges or fault-scarps, such as the Flamink Mountain, and consist of bluish quartzites, feldspathic quartzites, arkoses, and occasional conglomerates, all tending to weather purplish, together with some sericitic shales. (*c*) The Schwarzkalk is made of greenish shales, flagstones, thin quartzites, etc., with bands of dark limestones on several horizons, though variably developed. This group is not preserved in the south. (*d*) Alternating green and purple shales with thin quartzites, grits, arkoses, and conglomerates, the latter including pebbles of crystalline limestone, granite, quartz porphyry, and gneiss. Rogers termed these higher strata the "Ibiquas Beds,"[1] but Brink has proved a continuous passage upwards with impersistent conglomerates on various horizons. (*e*) Repetitions of dark bluish or purple shales and soft sandstones, showing false-bedding, ripple-marking, and worm-tracks form the highest zone and are seen in the east and in the Doorn River Valley—thus completing the parallel with the *Fish River Beds*.

Fossils and Age.—Apart from concretionary structures undoubted traces of life have been discovered in these strata. From the Kuibis quartzites at Groendoorn near Ham River Station, Gürich has described a medusa, *Paramedusium africanum*, and Haughton a cast having archæocyathid characters, which Gürich suggests may be a sponge like *Orthogonium*. Kuibis has provided curious impressions of doubtful affinities called by Gürich *Rangea schneiderhöhni*, *R.* (?) *brevior*, *Pteridinium simplex* and *Orthogonium parallelum*. Stromatopora-like forms characterise some of the limestones, *e.g.* in the Naukluft Mountains (Martin). Peculiar columnar, conical, and dentate structures from several horizons in the Otavi dolomite are regarded as possibly of algal origin by Schwellnus and le Roex. The upper part of the Dolomite has yielded to Schneiderhöhn remains that were viewed by Born as perhaps foraminiferal, and to Gürich a possible archaeocyathid.[2]

The Nama System is therefore either *Eo-Cambrian* or *latest pre-Cambrian*. Considered to be younger than the Transvaal System, it could conceivably be the part-equivalent of the Matsap

[1] *Ann. Rep. G.C. for* 1900, 25; *for* 1903, 149; *for* 1904, 32; *for* 1911, 49.

[2] G. Gürich, *XV Inter. Geol. Congr.*, 1930, pt. 2, 670; *Palæont. Zeits.*, 1933, xv, 137; S. H. Haughton, *The Geol. Warmbad District*, 1936, 26.

Formation, though the writer fancies that it may prove younger even than the latter, although it has been set below the Matsap in the Stratigraphical Table in Chapter II.

Tectonics.—The disturbances that affected the System in Van Rhynsdorp are of pre-Cape age, and trend north-north-west to north-west. They must apparently have resulted from renewal of those that affected the formations in the Lüderitz littoral, the strata of unknown age in the Olifants Valley, and the Malmesbury beds more to the south.

CHAPTER XI

THE CAPE SYSTEM

Introduction. Table Mountain Series. Bokkeveld Series. Witteberg Series. Cape System outside Africa.

Introduction.—The term Cape System is applied to the considerable thickness of sandstones, shales, and quartzites of Palæozoic age, which in the southern part of South Africa rest *unconformably* upon older formations and are followed in turn by the basement beds of the Karroo System. These rocks, the oldest in which recognisable fossils have been discovered, are confined to the southern half of the Union, extending from Van Rhynsdorp in the west round the coastal districts to the Kowie, but reappearing at Port St Johns and stretching through Natal into Zululand.

The true succession was made out by A. G. Bain in 1845, though he limited the Witteberg Series—his " Carboniferous "—to the Eastern Province; but the observations of Wyley and Dunn confirmed the three-fold grouping into :—

(3) The Witteberg Series—quartzites and subordinate shales with occasional plants of Devono-Carboniferous characters.

(2) The Bokkeveld Series—shales, flagstones, and sandstones with marine fossils of Devonian affinities.

(1) The Table Mountain Series—thick unfossiliferous grits and sandstones with scattered pebbles.

While its base is nearly everywhere markedly unconformable to the older or " pre-Cape " rocks, there is no stratigraphical break anywhere within this great mass of sediments 10,000 feet in thickness, nor even between the top of the Witteberg and the base of the overlying Karroo System in the southern part of the Karroo.

All three members have been involved in the intense folding which has affected the southern extremity of the continent, while the massive nature of the Table Mountain Sandstone has been responsible for the majority of the mountain ranges shutting off the Karroo from the sea, and for the same reason has determined

much of the present coast-line. Intrusive igneous rocks are rare in this System; they are almost entirely Karroo dolerites and restricted to the eastern area.

A. The Table Mountain Series

The Western and Southern Area: Basal Contact. Lithology. Shales. Glacial Zone. Eastern Region: Historical. Basal Contact. Thickness. Distribution. Lithology. Review of Series. Fossils. Age. Conditions of Deposition. Soils. Economics.

Since the broad belt made by this subdivision is for a considerable distance interrupted by the waters of the Indian Ocean, it will be more satisfactory to describe separately the two areas of the Cape and of Natal respectively.

1. The Western and Southern Area [1]

Distribution.—A description of the distribution of the Series will also serve as an account of the main structural features of the southern part of the Province, since nearly every important anticline is marked on the surface by a ridge of Table Mountain Sandstone.

The most northerly occurrence builds the table-topped Bokkeveld Mountain north-east of Van Rhynsdorp, the sandstones passing eastwards beneath the Dwyka conglomerate. Almost horizontal in the north, the Series becomes moderately folded in the south along axes trending east of south, a prominent anticline composing the Cedarberg (6648 feet) with the sandstones dipping eastwards below the slates of the Cold Bokkeveld (Fig. 37). The main range continues south in the grey Winterhoek Mountain (6818 feet) and the Hottentots Holland towards Cape Agulhas, while towards the west outliers cap the Malmesbury beds, as in the Riebeeks Kasteel and Table Mountain.

Near Ceres the north-south foldings become entangled with the east-west flexures of the south of the Cape (Fig. 3), and the Sandstone is thrown into arches and troughs along axes nearly north-south and east-north-east and west-south-west respectively, of which the Hottentots Holland and the Hex River and Zonder Einde (Sondereinde) Mountains are representatives. About

[1] For details see Rogers and du Toit, *The Geology of Cape Colony*, 1909, ch. vi.

Worcester the plan of the ranges is like that of a railroad "triangle," the north-eastern side being made by the magnificent Langeberg bounded on its south-western side by the gigantic Worcester Fault, through which the Sandstone has been brought up to make a range oblique to the trends of the principal axes of folding. The Langeberg turns east, broadening and becoming a compound anticline which, building the coastal range from George onwards, is known in successive sections as the Outeniqua, Zitzikamma (Sitsikamma) and Long Kloof Mountains. Isoclinal structure becomes common eastwards, brought out by the narrow infolds of Bokkeveld slates along which valleys have been eroded. North of Knysna the folds radiate eastwards but then bend in an east-south-easterly direction—parallel to the coast. Most of this country is formed of hard tilted sandstones and so the region from Uniondale onwards—known as the Kouga—is extremely rugged. East of the Gamtoos River the Sandstone composes the Cockscomb (5773 feet) and Winterhoek ranges, terminating along the shore at Port Elizabeth.

Well to the north of this great arcuate tract the sandstones reappear within Bokkeveld slates in the parallel and equally complex range of the Zwartberg (Swartberg). This commences in the west in the Anysberg and ends in the east near Willowmore as a simple anticline, but the foldings become more intense in between and the structures more involved as Oudtshoorn is approached; indeed between the latter town and Prince Albert the succession is mostly inverted with the southern side of the range faulted (Fig. 38).

The chain attains its maximum height of 7627 feet near Seven Weeks Poort and is cut through by a number of stupendous ravines of which the Gamka, Seven Weeks, Meirings and Toverwater poorts are the chief; by their means the drainage from the Karroo is enabled to pass through this barrier to the ocean. Between this and the parallel chain to the south various arches of sandstone rise, *e.g.* the Kamanassie Mountain (6421 feet). Most impressive scenery is produced in the Cape by this formation, for the magnificent gorges and precipices in these bare grey ranges display with remarkable clarity all the details of the foldings into which the sandstone layers have been bent (Plate XV).

Basal Contact.—The Series rests almost everywhere with strong discordance upon tilted Malmesbury beds or their intrusive

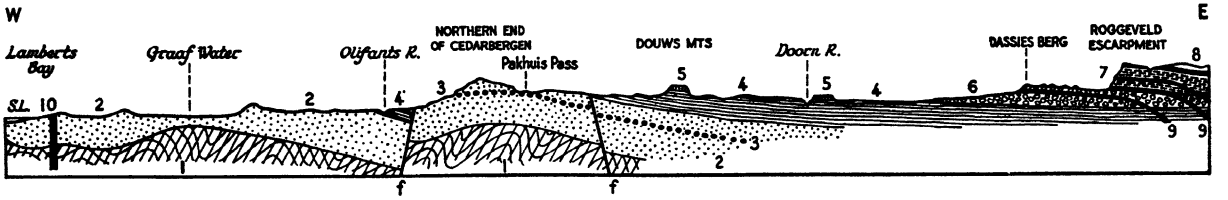


FIG. 37.—Section through the Cedarbergen and Roggeveld; length 105 miles. 1, Malmesbury Series; 2, Table Mountain Series with (3) shale band and glacial horizon; 4, Bokkeveld Series; 5, Witteberg Series; 6, Dwyka Series; 7, Ecca Series; 8, Beaufort Series; 9, Karroo Dolerite; 10, Volcanic Neck; f, Fault.

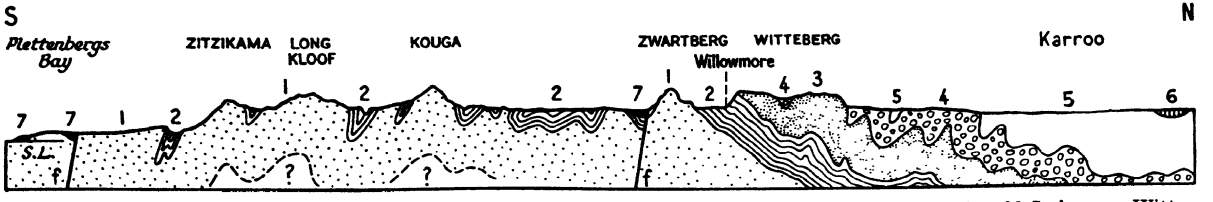


FIG. 38.—Section through the "Cape Fold Region," length 90 miles. 1, Table Mountain Series; 2, Bokkeveld Series; 3, Witteberg Series; 4, Dwyka Series; 5, Ecca Series; 6, Beaufort Series; 7, Cretaceous System; f, Fault.

granites (Plate XVI, 1), which indicates a lengthy period of planation anterior to the Devonian over a wide region. In the Humansdorp-Uitenhage area, however, this break is not obvious.

Only rarely is a basal conglomerate present, as in the Tulbagh-Swellendam area.

Thickness.—The figure, 5000 feet, usually given may perhaps be in excess of the general value; the thickness to the north of Clanwilliam is certainly less.

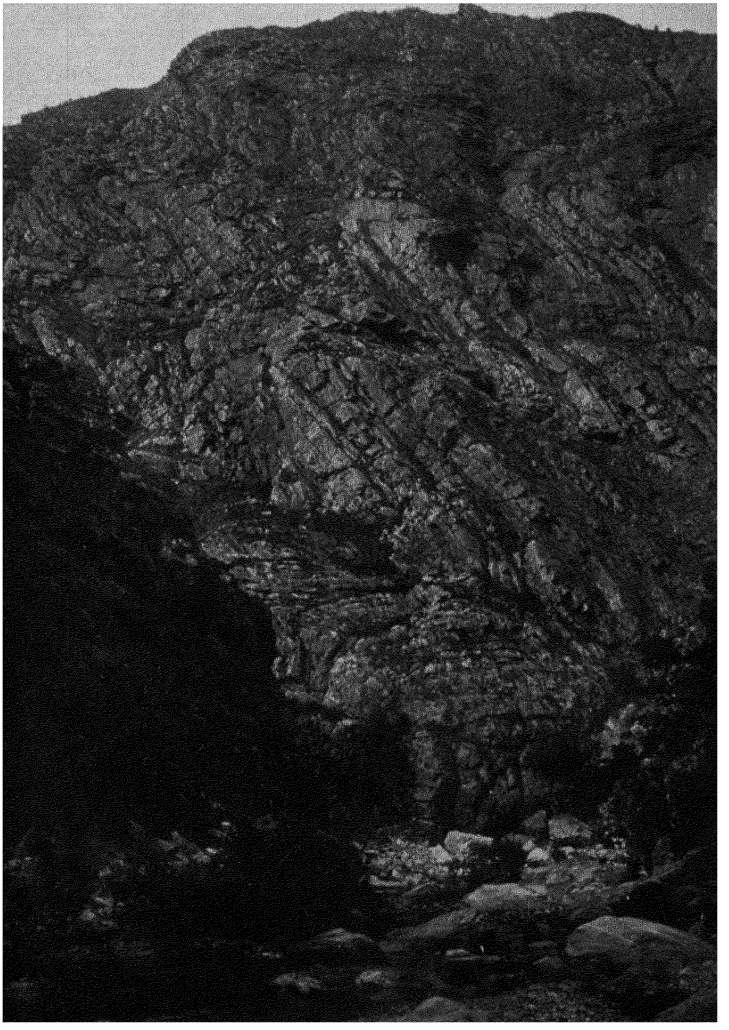
Lithological Characters.—The most conspicuous feature is the wonderfully constant character from base to summit despite the great thickness and extent, since, save for the relatively thin *Lower Shales* at or near the base and the *Upper Shales* at about three-fifths up in the succession, the Series is composed wholly of sandstone.

Both *Lower* and *Upper Sandstones* are dominantly whitish in colour and moderately coarse in grain, generally rather hard; indeed many of them, especially when fresh, could almost equally well be termed quartzites. In depth the stone is found to become grey or bluish-green, a character due to ferrous compounds, which are oxidised or removed in the surface zone and so give rise to whitish softer rocks with stains of red, yellow, or brown along the bedding planes or joints, where the sandstone has been impregnated with oxide of iron; dendritic markings are common.

The sandstone usually occurs in thick layers, which often show strong false-bedding, in places at high angles, while cross-jointing is common, becoming so well developed in the folded region that the stratification may only be discernible with difficulty, as at Port Elizabeth. On weathered faces the most fantastic outlines may be produced, more particularly in the huge pitted blocks strewing the slopes of the ranges. For these reasons the Table Mountain Sandstone builds greyish ramparts of rugged grandeur, which are distinguishable at a distance from those made by the whiter Witteberg quartzites.

Conspicuous are smooth, oval or rounded pebbles of white vein-quartz up to an inch or so in length—generally smaller—scattered irregularly through the sandstone though sometimes spread in discontinuous and thin layers.

Conglomerates are of rare occurrence, having been observed on the western face of the Piquetberg Mountain, on the right side of Verloren Vley, at Pikeniers Kloof (Clanwilliam), at Baboon Point on the coast,



Contorted and overfolded quartzites of the Table Mountain Series, a cliff about 400 feet high in Meirings Poort through the Zwartebergen, seen from the west.

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and in the Bokkeveld Mountain ; thin bands are also known in the Knysna and Uniondale districts. The pebbles are mostly of quartz and quartzite, though granite and quartz porphyry are occasionally to be seen. A striking constituent in the conglomerates of the Clanwilliam and Van Rhynsdorp districts is a brilliant red jasper, sometimes brown, and much like some *in situ* in Griqualand West.

The *Lower Shales* are developed locally not only in the Cape but in Natal as well. They occur at the very base with maximum thickness of 150 feet in the Cape Peninsula, but on a higher horizon in Piquetberg Mountain and farther north. Consisting of red and maroon micaceous shales and flagstones, they show sun-cracked surfaces and worm-castings.

The *Upper Shales*, though never more than 300 feet thick, are persistent, having been traced eastwards to the Uitenhage district. They are drab or bluish-green, though seldom exposed, their outcrop being normally masked by soil and rubble, producing a conspicuous grass-covered stripe amid the bare sandstone ledges (Plate XVII). The zone is important through furnishing evidence of contemporaneous glacial action, as detailed below. Bands of dark sandy shale up to about ten feet thick occur rather frequently in the railway sections across the Montagu Pass near George.

The Glacial Zone.[1]—In the Cedarberg, east of Clanwilliam the Upper Shale Band is about 300 feet thick, but the lowest third thereof consists of greenish-blue or reddish mudstone without lamination, containing scattered pebbles and boulders, which show flattened and striated surfaces like those of glaciated boulders (Plate XVIII, *b*). They are made of quartz, quartzites, sandstones, red jaspers, amygdaloidal diabase, and granite, and are distributed at random, irrespective of size, through a fine-grained matrix. In many respects the rock resembles the Dwyka tillite seen in the Karroo only a few miles to the east. The best localities are along the road over the Pakhuis Pass, on the slopes of the mountains on Klein Vlei and Lange Kloof, also Bosch Kloof on the south-western side of the Augsburg fault. The length of the lines along which these glacial beds have been followed near Clanwilliam is 23 miles.

On Bosch Kloof there is a gradual passage upwards from the usual coarse quartzitic sandstones with scattered white pebbles into the greenish-blue glacial rock, and the latter passes in turn into shale by

[1] For detailed descriptions, see *Ann. Rep. G.C. for* 1900, 79 ; *T.S.A.P.S.*, 1902, xi, 236 ; *ibid*, 1905, xvi, 1. E. H. L. Schwarz, *Journ. Geol.*, 1906, xiv, 686. S. H. Haughton, L. J. Krige, and A. V. Krige, *T.G.S.S.A.*, 1925, xxviii, 19.

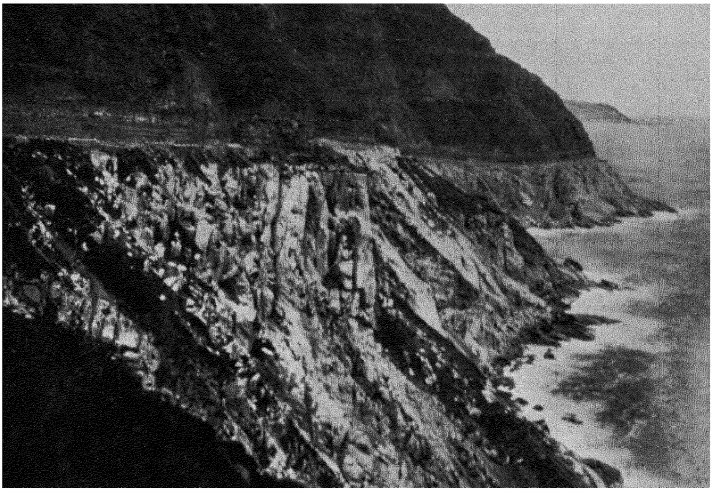
decrease in the number of the inclusions and by the appearing of lamination planes.

In Michell's Pass near Ceres the shales of this zone are only 150 feet thick and rather sandy, but pass downwards through some 20 feet of a dark cleaved bluish-green rock with quartz grains and occasional tiny pebbles into a rather unusual variety of gritty sandstone, white in outcrop, but bluish-green when fresh and quite unbedded though crossed by a strong cleavage ; below it passes into normal sandstone. Within this band are isolated pebbles, generally small but up to a foot in length, mainly quartz and quartzite, which are well striated and facetted, despite their small size and hardness. The matrix is much like the normal sandstone and the band can be regarded as a *glacial sand* with small erratics.

What must be the same horizon is found on the summit of Table Mountain itself, 2250 feet above the base of the series, for it is not unlikely that the Shale Band has only just been stripped off. The bed —a gritty quartzite—lies at the base of the knob on which Maclear's beacon stands, and the pebbles and boulders are mostly found weathered out from the intractable matrix and strewing the surface of the plateau. Many of them are only an inch or so in length and made of white quartz, but are nevertheless frequently " soled " and sometimes beautifully striated ; a few are much larger—up to a foot—and also scratched (Plate XVIII, *a*). The smaller ones were well waterworn before they were striated. Though white quartz and quartzite are most frequent, dark-coloured cherts, granite, black silicified rhyolite and a purplish gritty quartzite, very like those of the Matsap Series, were also found. The glacial zone is rather indefinite above as well as below, while it includes layers having irregular bedding and local unconformities. Among the pebbles are typical dreikanters.

Not only does this zone, with its gritty matrix and well-scratched inclusions, occur on Sneeuwkop and Victoria Peak near Stellenbosch, but it together with the sandstones beneath to the depth of as much as 200 feet have locally been squeezed into sharp folds. For explanation of this curious phenomenon with the truncation of the tops of some of the folds, although the strata farther down as well as higher up lie undisturbed, it is supposed that the ice-sheet must have passed over the still-unconsolidated glacial material and the sands below, rucked them up into folds and ploughed away their crests. Far to the east, on the northern side of the Zwartberg Pass, Haughton has discovered what appears to be its equivalent some 600 feet from the top of the Series, a horizon in the midst of shales carrying occasional small facetted pebbles.

The directions of the groovings run in different ways on different parts of the one pebble ; some fine instances of facetting have been noticed, while in quite a number of cases the inclusions have been



1.—Table Mountain Sandstone resting unconformably upon Granite, near Chapman's Peak, Cape Peninsula.

2.—Hell's Gates: Canyon of the Umzimkuluwana River cut through Table Mountain Sandstone resting on Granite, Alfred County, Natal.

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planed-down to an unusual degree. The glacials do not possess striated floors; probably at first the deposits were largely fluvio-glacial, but later the area became submerged and the pebbles were dropped by floating ice into the fine silts that were being laid down. The region supporting the glaciers was, so far as can be deduced, situated to the west or north-west.

2. The Eastern Region

Historical.—The generally white, but sometimes reddish, sandstone formation which stretches north-north-east from Port St Johns through Natal into Zululand was many years ago rightly correlated with the Table Mountain Sandstone of the Cape. Anderson in his First Report employed the non-committal term of "Palæozoic Sandstone," but later grouped it with the Table Mountain Series as did Rogers and Schwarz, and Hatch and Corstorphine, although the last two went further in correlating it with the Waterberg of the Transvaal. Schwarz put forward the view that there are really two groups of sandstones, the red one being the older—to be paralleled with the Waterberg—and the white being the younger—to be matched with the Table Mountain Series; this suggestion, however, has been controverted without difficulty.

Basal Contact.—As in the Cape the surface upon which the formation in Natal rests—principally granite and gneiss—is remarkably even (Plate XVI, 2) and represents a pre-Devonian peneplain.

This level character persists right up into Zululand, as far as the Qudeni, but is terminated on approaching Nkandhla by ridges of the hard Insuzi quartzites which stood up well above this ancient plain. Not only do the younger grits of the formation abut against this uneven terrain, but a coarser phase sets in, the troughs of the ancient valleys having been filled with red or chocolate-coloured conglomerates crowded with vein-quartz, quartzites, and occasionally jaspers, banded ironstones, etc., derived locally. They manifestly represent gravels deposited by the rivers debouching upon the peneplain that stretched towards the south.

In Hlabisa farther to the north-east this formation in similar manner rests in nearly horizontal attitude upon a diversified surface of granite, while conglomerates are locally developed at its base.

Thickness.—Nowhere have traces of the Bokkeveld Series been found in this region and, if ever they were laid down here, erosion must have removed them *prior* to the deposition of the

Dwyka tillite Not only did the Table Mountain Series undergo much denudation in this time-interval, but it also suffered a limited amount of tilting, and in Alfred County faulting.

The maximum thickness measured is nearly 4000 feet in eastern Pondoland with about 2000 feet in the Eshowe district. Over most of Natal more than 600 feet is rarely seen, while often merely a remnant intervenes between the Basement Complex and the overlying Dwyka tillite, with very considerable fluctuations, since the Dwyka abuts in places against ancient ridges carved out of the Sandstone or rests in hollows eroded in the latter.

The stratigraphical relationships here form a parallel with those in Van Rhynsdorp.

Distribution.[1]—Appearing first in the east-west " horst " of Port St Johns, a curious fault-block 7 miles long, the formation builds a wide terraced belt along the Pondoland coast, stretching into Natal. The structure right through this Province is a broad monocline in which the Karroo System has also been involved, while the attack of erosion upon the " hinge " of the flexure has generally produced a double belt. In the inland section the beds build plateaux and are lying nearly flat, while in the coastal section the sandstones dip seawards beneath the Karroo beds and sometimes form the actual shore.

Though the regularity of the two belts has been much interrupted by the intensity of erosion (as well as of faulting), some continuous stretches of sandstone country exist in the Murchison Flats, at Highflats, in Mid-Illovo, at Camperdown, New Hanover, Dalton, Mapumulo, Eshowe, and Melmoth. Pretty generally the sandstone makes characteristic ragged plateaux, bounded by scarps, in marked contrast to the formations above and below (Plate XVI, 2). Magnificent are the deep ravines of the Lower Umzimkulu, Umlalazi, Umgeni, and Umvoti rivers bordered by grey and red precipices, with the granite slopes below dissected into a maze of gigantic bush-clad furrows. Along the denuded axis of the monocline stand numerous tabular outliers that form links between the severed portions; among these are the Table Mountain near Maritzburg, and the Hlogozi, near Umzinto. Important outliers appear in Melmoth and Hlabisa, the latter making the most northerly occurrence known.

[1] See Geological Sheets 28 and 119, and the three Reports of the Geological Survey of Natal.

Matroosberg, Hex River Mountains, showing Upper Shale Band in Table Mountain Series.

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Lithological Characters.—The formation in Pondoland and in Alfred County is identical with the Series in the Cape; that is to say the sandstones are white, almost quartzitic, moderately coarse, poor in feldspar, often false-bedded, with scattered small pebbles of white or greyish vein-quartz and—in less amount—of pale quartzite. Tiny fragments, often subangular, of brilliant red jasper or of greenish cherty rock are found throughout Natal, though more abundant in the north, and thus recall the similar inclusions in the sandstone of the north-west of the Cape.

It is not uncommon also to find at the base in this eastern region some pebbly sandstones followed by from a few up to as much as 150 feet of red and maroon clay-shales, micaceous sandy shales, and flagstones just as in parts of the Cape.

Ignoring this basal development, the sandstones and grits in the extreme south are predominantly white, but reddish types make their appearance at various points farther to the north, so that in places the strata become plum-coloured or even a deep red. Along with this coloration a high proportion of feldspar is generally found; indeed some of the beds can be described as arkoses. The explanation is that the feldspar content has been derived from the waste of granitic and gneissic rocks, often rich in biotite and hornblende, minerals which would upon oxidation furnish a red ferruginous cement. On the contrary some of them have lost their colouring matter superficially through the reducing action of organic matter. Thin lilac- or mauve-coloured shales are occasionally seen.

The white sandstones are well developed around Highflats but, when followed towards the valley of the Umkomaas, are found to pass laterally into red feldspathic varieties. Right through Natal the pinkish type is the most common, though white sandstones are to be met with at many points; the beds in Hlabisa are generally white or grey in colour, gritty and feldspathic. Isolated quartz pebbles are a characteristic of this formation, and pebbly bands are to be found uow and again. About the pre-Cape "highland region" of Nkandhla coarse dark red and chocolate-coloured conglomerates make their appearance, generally near the base, with reddish-brown small pebbled conglomerates and grits higher up; they are purely local, being almost unrepresented 30 miles away.

3. Review of the Series as a Whole

Fossils and Age.—A curious feature is the unfossiliferous character of this thick formation. Both the greyish shales in the mass of the series and the red ones near the base have been

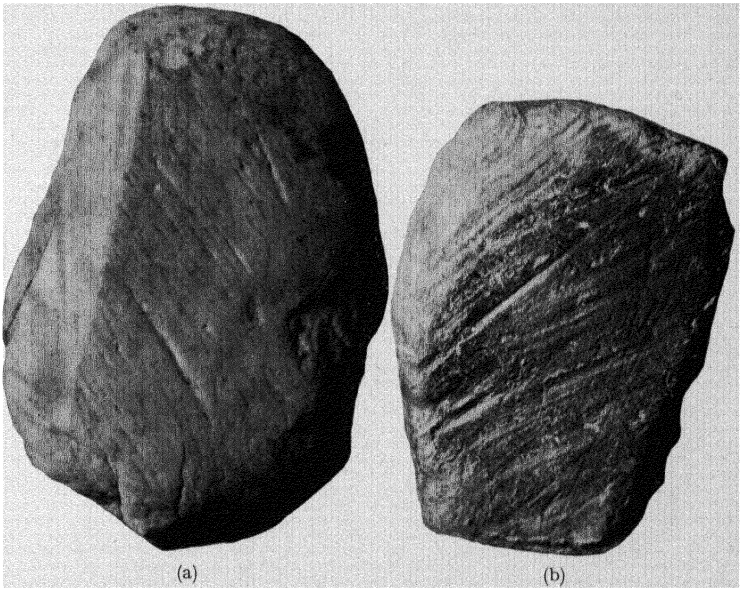
searched but, while casts of worm-burrows are common in the latter, only rarely have other traces been noted. Griesbach recorded some small bivalves and a finely striated *Patella* from this horizon on the western side of the Kranskop in Natal, but further search at this spot has so far been unsuccessful. Casts of supposed lamellibranchs have been got at Cape Town.

The age of the formation must consequently be fixed from that of the succeeding Bokkeveld Series, and hence may be taken as certainly not younger than the *Lower Devonian*, but from evidence from South America, where equivalent strata have yielded fossils, it probably ranges downwards into the *Upper Silurian*.

Conditions of Deposition.—The area which it covers or else underlies is immense for, though its northerly and westerly limits beneath the younger strata of the Great Karroo and of Natal respectively are unknown, the outcrops at Capetown are almost 1000 miles from those at Hlabisa, and those at Cape Agulhas a full 250 miles from those in Van Rhynsdorp.

That the region to the north of this belt was land in Siluro-Devonian times and furnished the sediment for the building up of the Table Mountain Sandstone is indicated by several lines of evidence : (1) the margin of the ancient peneplain can be studied in Zululand ; (2) the conglomerates are best developed and carry the largest pebbles in both north-west and north-east ; (3) the inclusions contain jaspers that can be matched among the pre-Cape rocks of the Northern Cape, Vryheid, and Zululand ; (4) the planes of false-bedding in Van Rhynsdorp mostly dip southwards, in the Cape Town-Bredasdorp area south-eastwards, and in Victoria County, Natal, quite regularly south-westwards (Kent) ; and (5) the sandstones as a whole become finer in grain towards the south, the pebbles becoming smaller and fewer, and thin bands of dark shale appearing in that direction.

The precise manner of deposition of this extensive body of dominantly arenaceous sediments is not quite assured. The region was presumably a " biological desert " because of the scarcity of vegetable life at that period. Æolian activity was rife as shown by the high angles of cross-stratification in certain bands. The uniformity, moderately coarse grain, prominent false-bedding, general absence of shaly layers and other peculiarities strongly recall the so-called " Nubian Sandstone Facies " of Egypt and Palestine. The region formed probably a vast coastal plain or series of broad deltas, studded



(*a*) Striated and facetted quartzite pebble from the Glacial Band, Table Mountain.
(*b*) Striated diabase pebble from the Tillite, Pakhuis Pass, Clanwilliam.

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by wandering dunes that were periodically levelled and reworked by rivers or ponded streams.

In the Cape and in Pondoland the iron compounds in the sands were reduced to the ferrous state, the feldspar grains decomposed and the resulting clay transported to the ocean. These facts point to erosion under a fairly high rainfall and to deposition upon a plain subjected to repeated flooding. With continued subsidence the ocean invaded the region and the blue-grey muds of the Bokkeveld Series were laid down, though in shallow water. The arenaceous bands in the latter become finer to the south, indicating that the land lay in the north.

Glaciers—possibly of no great size—for a time occupied some of the bordering mountains, and on melting yielded glacial silts—whence the Shale Band—followed by return to normal conditions.

For much of Natal and Zululand, however, the red feldspathic grits and sandstones associated with red mudstones and flagstones suggest a drier and warmer environment and a higher stand above sea-level, so that the sands had their iron minerals thoroughly oxidised. Comparison may be made with the Old Red Sandstone of Scotland, but the fish remains so characteristic of the latter are absent from the Table Mountain Sandstone, though found scantily in the succeeding Bokkeveld.

The Soils of the Table Mountain Sandstone.—In the Cape and in Pondoland the sandstones break down, though not too readily, to form a scanty whitish or grey porous sandy soil, dotted with tiny white quartz grains and small pebbles. Owing to their highly siliceous character and to their lack of feldspar, mica, or even clay, such soils are poor and "sour," supporting mainly grasses and reeds. A conspicuous feature of this formation is the bare character of the ranges which it builds, the protea or sugar-bush being the principal tree, though here and there on the seaward face of the ranges are patches of valuable forest, as for example at Knysna, Zitzikamma, Egosa, etc.

On flattish ground small ferruginous pellets are found in the surface layers, while not infrequently the ferruginous matter may constitute a well-defined bed of "lateritic ironstone," either as a crust or just below the surface; in the coastal region patches of "surface quartzite" are not uncommon. Owing to the general poorness of the soils there are relatively few farms under cultivation on the sandstone areas, while the mountain veld is mostly used for grazing.

In Natal rather the same soil-characters are to be found, though the more feldspathic nature of the sandstones is responsible

for a more coherent and slightly less unfertile soil. The rocks are more porous, and because of the much higher rainfall which occurs during the summer are frequently decomposed to considerable depths, as shown in railway cuttings; indeed, over much of the plateau-country outcrops may be few and far between, commonly along the stream beds, as in the Melmoth district. Much of the ground formed by this Series has been given up to the growth of wattles, for which it is fairly well fitted; moreover, it happens too that such tracts generally fall within the " mist-belt " of this Province.

As is only to be expected, the waters flowing off the Table Mountain Sandstone or obtained from springs, wells, or boreholes therein are remarkably low in mineral matter and therefore soft. Many Cape waters are, however, deep coffee-brown owing to the presence of organic compounds which are harmless for most purposes. Although commonly regarded as " pure " these waters are distinctly *acid*, having a pH value averaging about 5.7, and extremely corrosive in steam-boilers without special treatment. The Natal waters are clearer, though still acid.[1]

Economics.—The main value of this formation is that it furnishes a good rough *Building Stone*, though staining by iron oxides is not unusual. This is particularly the case in Natal where it is commonly softer and slightly reddish in tint; in the Cape the sandstone is white or yellowish, but is in many places traversed by planes of jointing or of shear, which may lead to much waste in quarrying. The rock is of little value as road metal.

Gold has been found in some of the conglomeratic layers, but always in small amount; also in quartz-veins in the much disturbed region of Knysna and along a broad zone of crushing at Hell's Gate in Alfred County, Natal.

The only considerable ore deposits are *Manganese* lodes at a number of places in the Western Province, *e.g.* Constantia Nek in the Cape Peninsula, Du Toits Kloof near Paarl, French Hoek, and Caledon. As mentioned on p. 532, they occur along zones of fracture and crush and have apparently been formed—probably largely from above—by the leaching of manganese compounds from the enclosing sandstones.

On account of the low porosity of the strata boreholes rarely give good supplies of *Water*; the decomposed feldspathic grits of Natal are slightly better in this respect. Nevertheless the highly jointed character of the hard sandstones is favourable to the passage of water

[1] The problem is discussed by G. W. Bond, *Union S.A.G.S.*, 1946, Mem. 41, 89-102.

wherefore the numerous little springs that flank the sandstone ranges. Indeed the majority of the large warm springs within the folded region of the Cape arise at or near the contact of the Table Mountain sandstone with the overlying Bokkeveld slates (p. 546).

B. The Bokkeveld Series

Historical. Distribution. Lithology. Cleavage. Soils. Fossils and Age. Faunal Relationships. Conditions of Deposition.

Historical.—Although fossil remains had been observed in this middle member of the Cape System so far back as 1837, only in 1859 did the name *Bokkeveld Beds* make its appearance —in Wyley's "Notes." This name was given them because of their typical development in the Warm Bokkeveld basin at Ceres.

It has been contended by several writers, Clarke for example, that the name "Bokkeveld" should properly be restricted to those beds containing marine fossils, and that the upper portion of the Series with its remains of plants ought to be grouped with the Witteberg. Though admirable for several reasons, the proposal is impracticable because of the impossibility of drawing such a line in the intricately folded region through the midst of beds of rather uniform lithological character and only scantily fossiliferous. A practically similar argument applies to the equivalent formations in the Falkland Islands and the Argentine, it should be noted.

Distribution.—Following *conformably* upon the Table Mountain Sandstone the beds first appear between Van Rhynsdorp and Calvinia, where they are lying nearly flat, being overlapped on the east by the Dwyka Conglomerate. Farther to the south the Witteberg Series comes in and the Bokkeveld Series, having attained its full thickness of about 2500 feet, acquires an easterly dip and makes a narrow strip of generally low-lying ground passing to the east of the Cedarberg, which more to the south is known as the Cold Bokkeveld, and finally drops down into the Warm Bokkeveld, terminating against the Table Mountain Sandstone at Verkeerde Vlei through the intervention of a fault. The outliers to the west all lie in valleys, and that in which Clanwilliam is situated is faulted on its north-eastern side (Fig. 37).

From the syncline of the Hex River valley the beds, repeatedly folded, extend eastwards to the Gouritz River, filling up the entire area between the Langeberg and the Zwartberg, but the main outcrop passes to the north of the latter in a very narrow belt to broaden out again at Willowmore. South of the Langeberg

so far down as Bredasdorp one finds a wide tract of open country made of folded slates, from Hawston in the west to Mossel Bay in the east, largely a partly dissected high-level peneplain (see Fig. 66).

South of Oudtshoorn there commences another belt which, interrupted only by the Kamanassie Mountain, stretches eastwards to Willowmore and continues past Steytlerville so far as the railway from Uitenhage to Bluecliff to reappear between Grahamstown and the Bushmans River. In Pondoland and Natal this formation has not been discovered and may never have been deposited there.

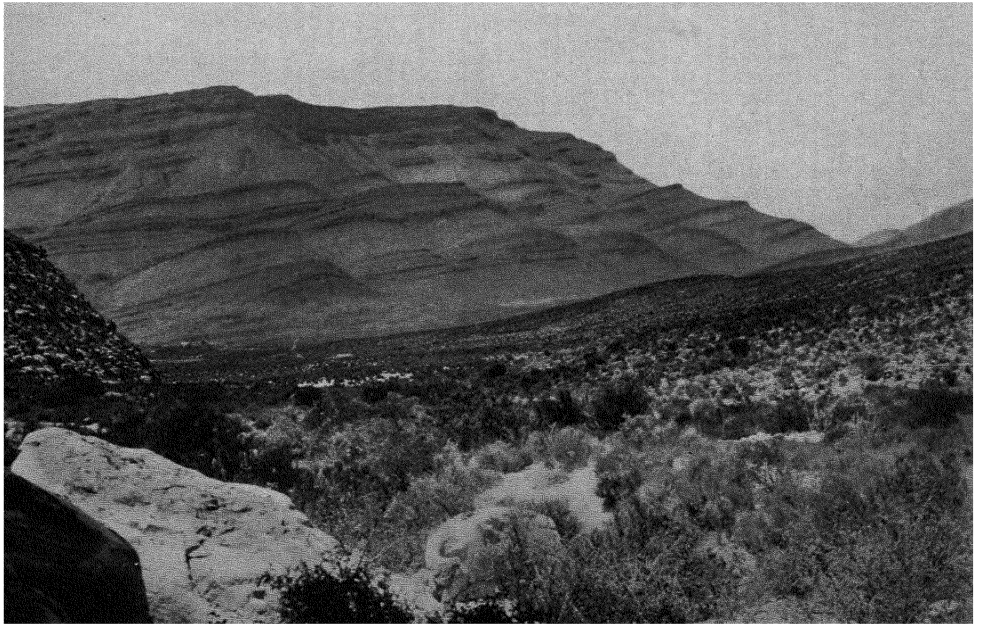
In the mountainous territory between George and Port Elizabeth quite a number of narrow but important strips of slates occur deeply infolded with the Table Mountain Sandstone, as for instance at Knysna, Uniondale, the Long Kloof, and in the Elands River valley. By reason of their softness they have produced valleys in this rugged territory which form the principal means of communication and at the same time yield the only arable land in this rocky region.

Lithology.—When typically developed, as towards the north-west, there are *five* dominantly argillaceous groups each several hundreds of feet in thickness separated from one another by *four* thinner groups from 100 to 400 feet thick of sandstones and quartzites.

The softer strata consist largely of dark bluish to blackish, greyish, and greenish shales and mudstones with some micaceous flagstones and thin brownish soft feldspathic sandstones (greywackés), but limestones are unrepresented, though impersistent brown calcareous layers are occasionally to be found; all are much cleaved. This alternation of softer and harder zones shows up conspicuously in the topography, the sandstones producing a regular series of low ridges or scarps as in Plate XIX, and littering the shale slopes with their fragments.

The shales forming the lowest of the groups are rather dark, sometimes carbonaceous, and fairly rich in fossils, particularly in certain ochreous concretionary nodules. Their junction with the Table Mountain Sandstone, where exposed—which is by no means common—is generally sharp, as at the entrances to Gamka Poort or Meirings Poort.

The first sandstone zone is soft, brownish or reddish at the outcrop, and feldspathic in character, though bluish when fresh, and hence is not conspicuous in the landscape; it frequently contains



Blinkberg in the Cold Bokkeveld. Table Mountain sandstone in foreground; ledges of the Bokkeveld sandstones seen in slopes, which are crowned by precipices of Witteberg quartzites.

[Face page 250

casts of mollusca, particularly of *Spirifer* and *Leptocœlia*, and consequently is often referred to as the "Fossiliferous Sandstone."

The second group of shales is like the first, but the third is generally more micaceous and but rarely contains mollusca. The second, third, and fourth sandstones are false-bedded, greyish or whitish and somewhat quartzitic and make strong outcrops; the second occasionally carries fossils. Only some badly preserved plant fragments have been obtained from the fourth and fifth shale zones. Graphitic slates carrying plant remains were prospected many years ago for coal near the Kowie. Near the summit the shales become distinctly more flaggy and micaceous, thin sandstones and pale, fine-grained quartzites appear, and the whole passes up without any discordance into the thick white quartzites of the Witteberg Series.

While such alternation of shale and sandstone zones prevails from the type region southwards to the Langeberg and eastwards to Klaarstroom at least, the sandstones become finer grained when followed to the south, so that in Caledon, Heidelberg, Riversdale and Uitenhage those members become hardly recognisable, the Bokkeveld becoming almost wholly argillaceous. Indeed even the Witteberg becomes more shaly in that quarter, so that to the south of the Langeberg, where the strata are intensely folded and cleaved, the upper limit of the Bokkeveld as shown on the Geological Survey maps is merely approximate.

Cleavage.—Owing to their fine grain and soft character the Bokkeveld shales in the folded region usually possess a strongly developed cleavage converting them into slates; quartz-veining is common. Such cleavage planes have an approximate west-east strike and a high dip towards the south, the structures having been produced by the intense crustal pressure under which the folding and overturning within the coastal region were brought about. To such an extent is this the case that it is often only possible to make out the contorted stratification through the presence of certain sandy and therefore more resistant bands. The fossils have suffered considerable distortion and in many parts of the folded belt they have been sheared almost out of recognition.

Soils.—The names Warm and Cold Bokkeveld given to the more fertile valleys in the mountainous region at and to the north of Ceres showed the recognition by the early settlers of the better quality of the soils produced by this formation as compared with those yielded by the other members of the Cape System. Very fortunately, owing to their softness, the beds are mainly restricted to the valleys and consequently occupy positions favourable for soil production, although on the other hand they

are liable to be smothered by or at least blended with siliceous sands derived from the adjacent quartzite heights.

The series being essentially argillaceous, the soils therefrom are rather clayey, usually drab or light brown in colour, more rarely reddish, with a subsoil possessing much partially weathered slate ; small irregular fragments of vein quartz are quite a typical feature. The small amount of calcareous matter in the beds leads to a " sweet " soil, consequently the general absence of " sour " grasses and proteaceæ and universal presence of rhenoster bush (*Elytropappus*) and boterboom (*Cotyledon*). Such is the contrast in the soils that in the highly folded terrain in Willowmore and Uniondale strips of slate not many yards wide in the sandstone can be detected from afar by reason of the denser growth of the vegetation on them. Small springs issue from the slates at many points, but the waters are not infrequently slightly sulphuretted.

Fossils and Age.—The *lower three-fifths* of the Series has alone yielded fossils of marine types, the *upper two-fifths* having furnished only some poorly preserved plants. While the former are obtainable at many points between Nieuwhoudtville in the north-west and Grahamstown in the east, fossils are certainly scarce, especially in the extreme south, or have been much distorted through earth-pressure. Rarely has the actual shell substance been preserved, there being generally either an impression or a hollow mould ; the latter is usually the case in the " Fossiliferous Sandstone," which is sometimes crowded with ochreous casts of *Spirifers*. Those forms enclosed within small nodules are always well preserved (Fig. 39).

Among the brachiopods are abundantly represented *Chonetes, Leptocœlia, Lingula, Orbiculoidea, Rensselæria, Schuchertella* (*Orthothetes*) and *Spirifer* ; among the lamellibranchs appear *Actinopteria, Grammysia, Janeia, Modiomorpha, Nuculana, Nuculites, Palæoneilo*, and *Sanguinolites* ; chief among the trilobites are *Homalonotus* and *Acaste* ; gasteropods are rare—*Bellerophon* and *Loxonema; Orthoceras* is the only cephalopod, while the pteropods are represented by *Conularia* and *Tentaculites*. The spine of a fish marks the earliest vertebrate in South Africa.

The studies of this fauna indicate an age for the lower half of the Bokkeveld Series which is *Lower* and probably *late Lower Devonian* ; the upper half belongs palæontologically to the Witteberg Series.

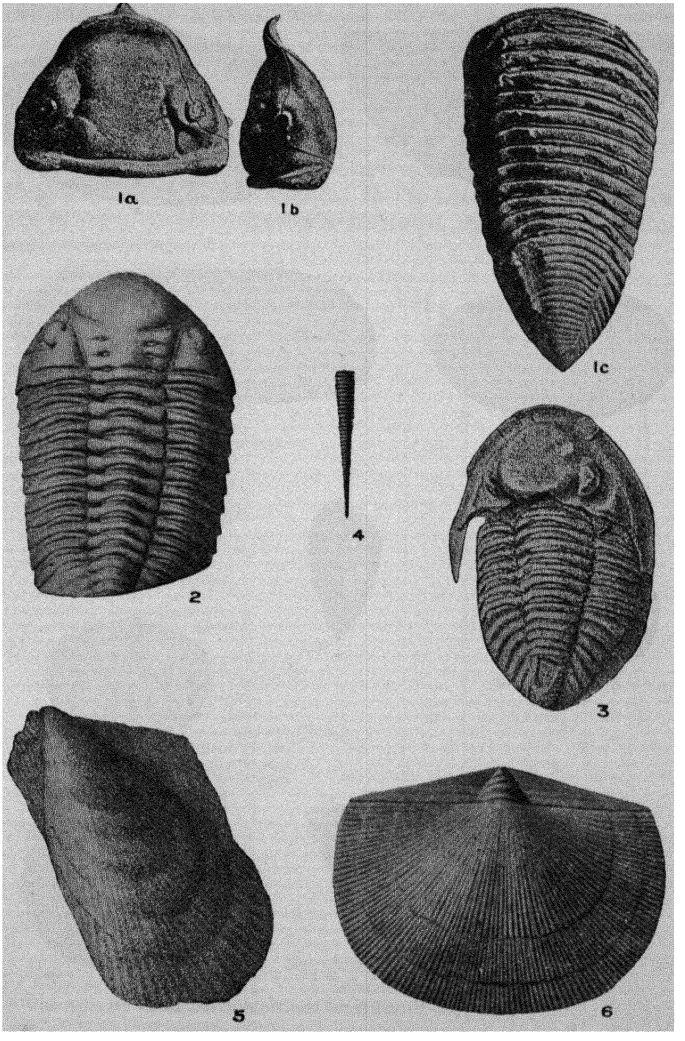


FIG. 39.—Fossils from the Bokkeveld Beds.

1a, 1b. *Homalonotus herscheli*, head. Half natural size.
1c. *Homalonotus herscheli*. Body and tail.
2. *Acaste* (*Phacops*) *ocellus*. Natural size.
3. *Proetus malacus*. Natural size
4. *Tentaculites crotalinus*. Natural size.
5. *Actinopteria eschwegii*. ×One and a half.
6. *Schuchertella sulivani*. Natural size.

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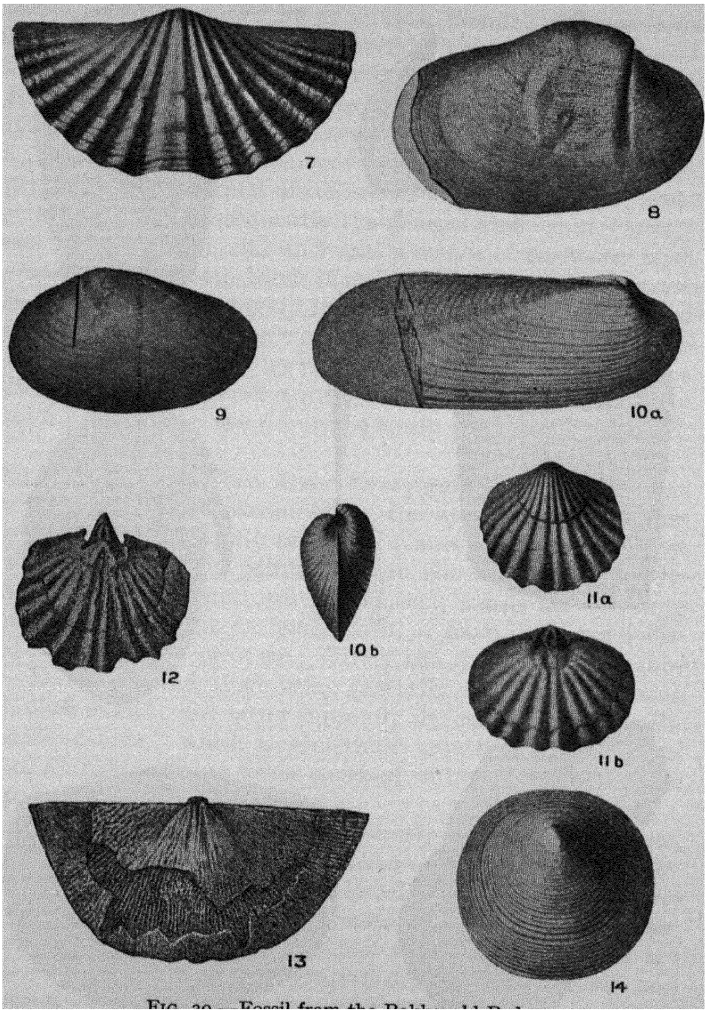


FIG. 39.—Fossil from the Bokkeveld Beds.

7. *Australospirifer (Spirifer) antarcticus.* Natural size.
8. *Nuculites pacatus.* Natural size.
9. *Nuculites sharpei.* Natural size.
10a, 10b. *Janeia bokkeveldensis.* Natural size.
11a, 11b. *Leptocœlia flabellites*, exterior. Natural size.
12. *Leptocœlia flabellites*, interior cast. Two-thirds natural size.
13. *Chonetes falklandicus.* Natural size.
14. *Orbiculoidea baini.* Natural size.

1, From Salter; 3, from Lake; 5, 12, 13, from Reed; 2, 4, 6-11, 14, from Clarke

It would now appear that the fragments of the eurypterid *Hastimima*, the crustacean *Palæestheria* and certain plant impressions actually came from the top of the Bokkeveld beds.[1]

List of Fossils.—The fauna, which had been described principally by Reed and Lake, was reviewed by Clarke in 1913. A revision was made by Reed in 1925, though not all the new forms have been incorporated in the following comparative table. In the latter the presence outside South Africa of identical species is indicated by an *x*, and of closely allied species by an *a*.[2]

	Falkland Islands.	Argentina.	Brazil and Uruguay.	Bolivia.	North America.
Vermes :—					
Serpulites sica Salter	..	..	x		
Taonurus cauda-galli (Vanuxem)	..	..	..	..	x
Sponge :—					
Clionolithus priscus M'Coy	x	..	x		
Coral :—					
Zaphrentis (?) *zebra* Schwarz.					
Ophiuroid :—					
Ophiurites sp.					
Crinoid :—					
Ophiocrinus stangeri Salter.					
Cystids :—					
Placocystis africanus Reed.					
Placocystella capensis Rennie.					
Trilobites :—					
Acaste (*Calmonia*) *africana* (Shand).					
,, (,,) *callitris* (Schwarz)	..	..	a	a	
,, (,,) *lakei* (Reed)	..	..	a		
,, (,,) *ocellus* (Lake)	x	..	x		
,, (*Acastella* ?) *pseudoconvexus* (Reed)	..	..	..	a	
,, (*Phacopina*) *hiemalis* (Reed).					
,, (*Pennaia*) *impressus* (Lake)	..	..	a		
,, (*Proboloides*) *ensifer* (Reed).					
Acidaspis atherstonei Reed	..	..	..	a	
,, *capensis* Reed.					
Bainella acacia (Schwarz)	..	..	a		
,, *baini* (Reed).					
,, *bokkeveldensis* Rennie.					
,, *cristagalli* (Woodward).					
,, *gamkaensis* Rennie.					

[1] J. V. L. Rennie and E. D. Mountain, *T.R.S.S.A.*, 1942, 59; A. S. Woodward, *Geol. Mag.*, 1909, 486; J. V. L. Rennie, *S.A.A.A.S.*, 1934, xxxi, 233.

[2] The species mentioned are described in the following papers: Salter and Sharpe, *T.G.S.*, 2nd series, 1856, vii, 203; Woodward, *Q.J.G.S.*, 1873, xxix, 31; Lake, *Ann. S.A. Mus.*, 1904, iv, 201; Reed, *Ann. S.A. Mus.*, iv, 165; and *ibid.*, 1904, iv, 239; 1908, iv, 381; 1925, xxii, 27; *Geol. Mag.*, 1907, 34, 165, 222; Schwarz, *Rec. Alb. Mus.*, 1906, i, 347; Clarke, *Serv. Geol. Min. Brasil*, Monogr. i, 1913; Shand, *T.G.S.S.A.*, 1914, xvi, 24; R. Kozlowski, *Ann. de Palæont*, 1923, xii, 1; J. V. L. Rennie, *T.R.S.S.A.*, 1930, xviii, 327; R. Mendez-Alzola, *Inst. Geol. Uruguay*, 1934, Bol. 21, 21; 1938, Bol. 24, 3; K. E. Caster, *Proc. Eighth Amer. Sci. Cong.*, 1941, 27.

	Falkland Islands.	Argentina.	Brazil and Uruguay	Bolivia.	North America.
Trilobites (*contd.*) :—					
Cyphaspis dereimsi Kozlowski	..	..	..	x	a
Dalmanites (*Metacrypheus*) cf. *australis* Clarke	..	..	x	x	
,, (,,) *caffer* (Salter)	..	..	..	a	
Homalonotus (*Digonus*) *fontinalis* Reed.					
,, (,,) *noticus* Clarke	..	x	x	x	
,, (*Burmeisteria*) *herscheli* Murchison	x	..	a		
,, (,,) *quernus* Lake.					
Phacops (*Bouleia* ?) *sharpei* Reed.					
Proetus hexensis Reed.					
,, *malacus* Lake	..	..	..	..	a
Typhloniscus baini Salter.					
Brachiopods :—					
Ambocœlia pseudoumbonata Kozlowski	..	..	..	x	a
Australospirifer antarcticus (Morr. and Sharpe)	x	x	x	x	
Chonetes falklandicus Morr. and Sharpe	x	x	x	x	a
,, cf. *hallei* Clarke	a				
,, *stübeli* Ulrich	..	..	..	x	
,, aff. *arcuata* Hall	..	..	..	..	a
Cryptonella baini (Sharpe)	x	..	x	x	a
Derbyina hottentot (Schwarz).					
,, *simplex* (Schwarz).					
,, *variegata* (Reed)	..	..	a		
,, *whitiorum*, Clarke	..	x	x		
Leptocœlia flabellites (Conrad)	x	x	x	x	x
Lingula keideli Clarke	..	..	x	a	
,, *lepta* Clarke	..	x	x		
,, *scalprum* Clarke	..	..	x	x	
Meristella cf. *riskowski* Ulrich	..	..	..	x	a
Orbiculoidea (*Roemerella*) *baini* (Sharpe)	x	..	x	x	a
,, (,,) cf. *collis* Clarke	..	..	a		
Rennselæria montaguensis Reed	a	..	..	..	a
,, *relicta* Schwarz.					
,, *rotundata* Reed.					
Rhynchonella (*Clarkeia*) *bodenbenderi* (Kayser)	..	x	..	x	
Scaphiocœlia africana Reed	x	..	x	x	a
Schuchertella sulivani (Morr. and Sharpe)	x	x	x	x	a
Spirifer ceres Reed	..	x	x	x	
Stropheodonta arcei Ulrich	..	..	x	x	
,, cf. *katzeri* Knod	..	..	a		
Vitulina pustulosa Hall.					
Lamellibranchs :—					
Actinopteria eschwegii Clarke	..	x	x	x	
Buchiola subpalmata Reed.					
Ctenodonta grahami Reed.					
,, *stowi* Reed	..	..	..	..	a
Goniophora gydowensis Reed.					
Grammysia (*Grammysioidea*) *corrugata* (Sharpe).					
,, (,,) *campestris* (Reed)	..	..	..	x	
,, (,,) *fontinalis* (Reed).	..	..	a		
,, (,,) *montana* Reed	..	..	..	..	a
Janeia baini (Sharpe)	..	..	a		
,, *bokkeveldensis* (Reed).	..	..	x		
,, *braziliensis* Clarke	..	..	x		
Modiomorpha cf. *austronotica* Clarke	..	..	a		
,, *hexensis* Reed	..	..	a		
,, *lunulata* (Schwarz)	..	..	a		
,, *montaguensis* Reed.					
,, *nigra* (Reed).					
,, cf. *scaphula* Clarke	..	..	a		

	Falkland Islands.	Argentina.	Brazil and Uruguay.	Bolivia.	North America.
Lamellibranchs (*contd.*) :—					
Myalina brevicardinalis Reed.					
Nuculana agrestis Reed	..	..	x	x	a
,, *inornata* (Sharpe)	..	..	a		
,, *viator* Reed	..	..	x	a	
Nuculites abbreviatus (Sharpe).					
,, *africanus* (Sharpe)	..	..	a		
,, cf. *beneckei* Ulrich	a	..	a	a	
,, *capensis* Reed	..	..	x	x	
,, *martialis* Reed.					
,, *oblongatus* Conrad	..	..	x	x	
,, *obtusus* Reed	..	..	a	a	
,, *pacatus* Reed	x	..	x	a	
,, *sharpei* Reed	x	..	x	..	a
,, (*Ditichia*) *colonicus* Reed	..	..	..	..	a
Palæoneilo antiqua (Sharpe)	..	..	a		
,, *arcuata* Schwarz	..	..	x	..	a
,, *orbignyi* Clarke	..	..	x		
,, *rudis* Sharpe	..	..	a		
,, *sanctricrucis* Clarke	..	..	x		
,, *subantiqua* Reed	..	..	a	x	
,, *vindicata* Reed	..	..	a		
Præcardium bokkeveldense Reed.					
Sanguinolites albanus Reed.					
Sphenotomorpha bodenbenderi (Clarke)	..	..	a		
Gasteropods :—					
Bellerophon (*Plectonotus*) *fraternus* Reed	..	..	a		
,, (,,) cf. *dereimsi* (Knod)	a	..	a	a	a
,, (,,) cf. *laticarinatus* (Knod)	..	a	..	a	
,, (,,) *quadrilobatus* Salter	x	..	..		
,, (*Patellostium*) *africanoides* Reed	..	..	a	..	a
,, cf. *morganianus* Hartt and Rathbun	..	..	..	..	a
Diaphorostoma baini (Sharpe)	x	..	x	x	
Loxonema capense Reed	..	..	..	a	
,, *zwartbergense* Reed.					
Metoptoma capense Reed.					
Platyceras bokkeveldense Reed	..	..	..	..	a
Pleurotomaria aff. *kayseri* Ulrich	..	..	a	a	a
Pteropods :—					
Conularia africana Sharpe	x	..	x	x	a
,, *baini* Ulrich	..	..	a	x	
,, *gamkaensis* Reed.					
,, *quichua* Steinm. and Död	..	x	x	x	
,, *ulrichana* Clarke	..	..	x	x	
Hyolithes d'Orbignyi Kozlowski	..	..	..	x	
,, *subæqualis* (Salter)	..	..	x	..	a
Tentaculites baini Reed	..	..	..	..	a
,, *crotalinus* Salter	x	x	x	x	
,, *desuetus* Reed.					
Cephalopods :—					
Orthoceras bokkeveldense Reed	..	..	..	a	a
,, *gamkaense* Reed	x	..	x	a	
,, *rex* Schwarz	..	..	..	a	
Fish Spine :—					
Machæracanthus sp.					
Crustaceans :—					
Hastimima.					
Palæestheria.					
Plants :—					
Haplostigma irregulare (Schwarz).					
"*Bothrodendron*" sp.					
Dutoitia pulchra Hoeg.					

Faunal Relationships.—The similarities manifested to the American, more particularly the South American, Devonian faunas and the contrast with the apparently contemporary assemblages in Europe has long been remarked upon and is striking indeed, though Haug [1] has also described among others some forms typical of the Bokkeveld from Devonian beds in the Sahara and Allan [2] some from New Zealand. Reed in discussing the Bokkeveld fauna in 1925 concluded that it was related more to the Lower than to the Middle Devonian of North America, and that although the resemblances were close to the Lower Devonian (Coblenzian) of Europe there were no species identical with those of the latter.

Clarke, in 1913, emphasised the point that the faunas of South Africa, the Falkland Islands, Argentina, southern Brazil, and Bolivia have each what could be termed an *Austral impress* as compared with those of northern Brazil, North America, and Europe, which exhibit a *Boreal aspect.* In the former the fauna is essentially *a unit* and represents only the *early* Devonian, there being a remarkable absence of faunal zones throughout the entire thickness of the formation, such as characterise the boreal facies elsewhere. Apparently isolation in the south led to a sudden and peculiar evolution among the trilobites and brachiopods, especially the *Spirifers.* Schuchert places these faunas in the *upper part of the Lower Devonian.*

Although future collecting may cause us to modify our conclusions, the present list will serve to show that the Bokkeveld fauna, though having an individuality of its own (Reed), is related rather closely to those of the Falkland Islands and southern Brazil, also to those of Bolivia and Argentina. Comparing the mollusca solely, the number of common or allied species is highest with Brazil, but about equal in the case of Uruguay, Bolivia, and the Falklands. On the other hand, considering the trilobites alone, there is only one species common with Brazil, whereas no less than four Bokkeveld species are represented in the Falklands and two in Uruguay and Bolivia.

Conditions of Deposition.—While the lower half of the Bokkeveld beds was deposited under the sea, the frequent occurrence of false-bedding in the sandstones and the absence of limestones indicate shallow-water conditions somewhat like those of the Alpine Flysch, a deduction supported by the scarcity of remains of deep-sea organisms, such as crinoids and corals. It has been concluded, for reasons already stated, that the land lay to the north : continued subsidence must have carried the fluviatile sandy accumulations of the Table Mountain Series below sea-level

[1] E. Haug, *Comptes Rendus,* 1905, cxli, 970.
[2] R. S. Allan, *Geol. Surv. New Zealand,* 1935, Palæont. Bull. 14.

in the southern part of the Cape, though quite possibly the sandstones of Natal and Zululand remained unsubmerged. Oscillations of the sea-floor are suggested by the marked alternation of arenaceous and argillaceous zones.

A shallowing of the sea during the later stages of the Devonian is denoted by the disappearance of the mollusca and incoming of plants in the upper part of the Bokkeveld, while the deposition of the succeeding Witteberg quartzites indicates the restoration of estuarine or fluviatile conditions.

C. The Witteberg Series

General. Distribution. Lithology. Delimitation. Fossils and Age.

General.—The formation takes its name from the Wittebergen, a range bordering the Karroo to the south of Laingsburg and Prince Albert, the bare, white, rocky slopes of which are built up of these beds in which quartzites play a very important part, quite overshadowing the softer flagstones and shales. Indeed, because of that character they give rise to chains of bare contorted quartzites, though curiously with even crest-lines generally, while the slopes and flats may be thickly strewn with shed lumps of quartzite. The soil is always scanty and the pasturage on the hills invariably poor. In the extreme east owing to the somewhat higher rainfall the vegetation is more abundant, although acacias, aloes, and euphorbias still predominate in the flora.

Distribution and Relationships.—Passing downwards *conformably* into the Bokkeveld (Plate XIX) and overlain by the Dwyka tillite they commence in the north-west almost on the 32nd parallel and stretch southwards in a broad belt of bare mountain-country known as the Swart Ruggens, the strata usually dipping at low or moderate angles, though traversed by occasional sharp kinks or "knee bends" or local contortions. Some of this crumpling was certainly produced prior to the deposition of the Dwyka glacial beds, which in the northern section rest *unconformably* upon the quartzites. Near Karroo Poort, however, the Witteberg passes upwards through the medium of the Lower Dwyka Shales[1] into the glacial conglomerate and henceforward

[1] The beds here called Lower Dwyka Shales are now considered by the Geological Survey to form part of the Witteberg Series and are re-named the Upper Witteberg Shales (Editor's Note).

right through to Grahamstown both are conformable and involved in the Cape foldings.

At Karroo Poort the belt turns eastward and widens at Touws River with strata repeatedly folded, to continue in the narrow but remarkably even-topped Wittebergen, a treeless wall of quartzites running with wonderful regularity past Prince Albert and Willowmore to Steytlerville. Here folding has brought about the duplication of the belt in a chain that passes close to Klipplaat, beyond which it gets broader and higher, and so forms the Zuurberg (Suurberg), curving towards the south-east and dropping to the coast at the Kowie, while a parallel arch makes its appearance to the north of Grahamstown.

The pitching of the deep foldings by which the Witteberg and the Dwyka are traversed causes the anticlinal ridges of quartzite to plunge beneath the softer Dwyka Series, and the ridges made by the former tend therefore to be arranged *en échelon*. Examples of fine quartzite arches often overturned to the north are common, as for instance that shown in Plate XX on the Sundays River, near the Lake Mentz irrigation dam. This river cuts nearly transversely through the ranges, as is also the case with the Buffels and Gamka, but the Gamtoos has very largely followed synclinal troughs crossing the mountain chain obliquely.

By intense down-faulting the formation appears in the Worcester-Robertson area in the Roodeberg, plunging northwards beneath the Karroo beds of the Breede (Breë) River valley, while other patches are folded in along a strip following the Zonder Einde (Sondereinde) River, and again between Swellendam and Riversdale. The southernmost outcrops are at Marthas Point east of Bredasdorp.

Lithology.—The white quartzites so characteristic of this formation are universally very fine in grain, more thinly bedded than the Table Mountain sandstone and much whiter, but tending to weather with reddish crusts. Together with the shaly beds they have been bent into the most acute folds, generally without having suffered fracture, the flanking or intercalated shales having accommodated themselves to the bending of the hard quartzite ribs ; the bedding planes of the latter are frequently striated as the result of the slipping of the layers one over the other owing to such internal movements.

The shales and flagstones are commonly micaceous and dark

[Face page 260

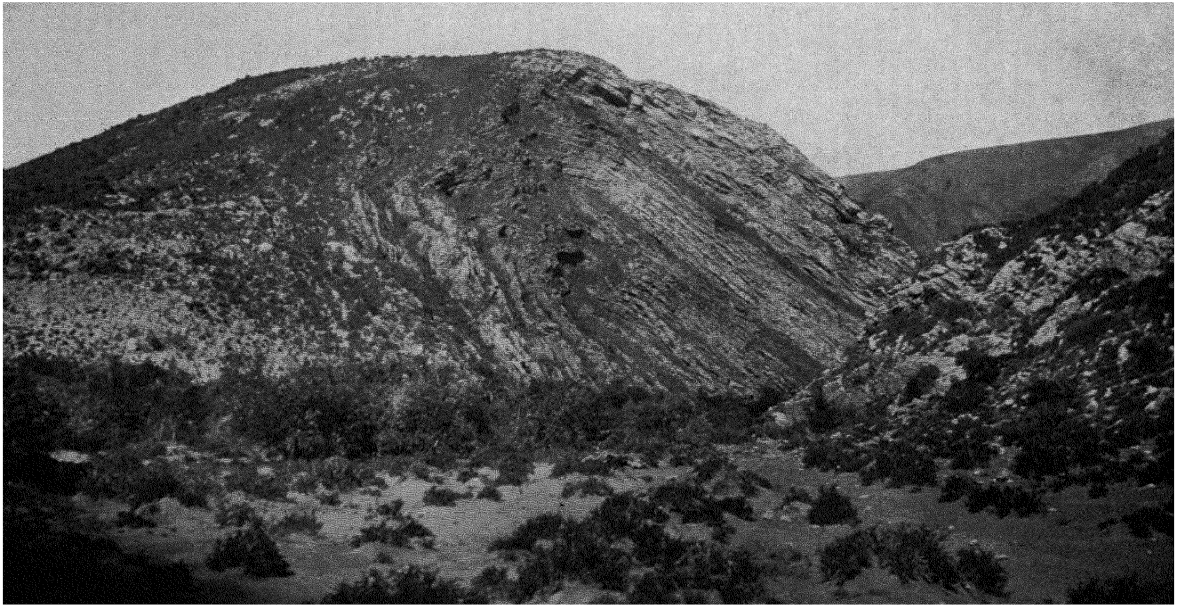


PLATE XX

Anticline of Witteberg Quartzites overturned towards the north on Sundays River below the Lake Mentz Dam. The flat-topped Zuurberg Range appears in the background.

green or blue and are sometimes carbonaceous, but are bleached at the outcrop to light green or buff. Now and again thin brown-weathering lenses of grey sandy limestone or calcareous quartzite are present in the upper part of the Series, occasionally carrying plant fragments; they may be associated with bands of a coarse grit.

Like the other members of the Cape System the Witteberg beds become finer grained south of the Langebergen. Moderately shallow fresh water is indicated, deepening towards the south.

Delimitation of Series. — As defined it is about 2500 feet in thickness.

Its delimitation from the Bokkeveld Series below is not always easy, since the latter become flaggy near the top before the main group of quartzites is reached; while the fossil "*Spirophyton*," once supposed to be restricted to the Witteberg, is now known from the top of the Bokkeveld.

Upwards, the main quartzites of the Witteberg are separated from the Dwyka tillite by close upon a thousand feet of shaly and flaggy beds containing one or more horizons of fine-grained white or greyish quartzite, the *uppermost* of which has been chosen for the base of the Lower Dwyka Shales. It must, however, be admitted that the boundary so selected is a purely arbitrary one, and that it would have been more satisfactory had the Lower Dwyka Shales been grouped with the Witteberg and the Dwyka Series taken as commencing with the tillite, the base of which is almost everywhere sharply defined. (See foot-note on p. 259.)

Fossils and Age.—Fragmentary remains of plants are found as casts or poor impressions and little weight can therefore be placed on the older records[1] of *Bothrodendron*, *Lepidodendron*, *Cyclostigma*, *Halonia*, etc. Cortical impressions have been described as *Haplostigma irregulare* (Schwarz). A common form—present in the Upper Bokkeveld as well—is "Spirophyton," a fucoid-like impression extending spirally through several inches of rock with the curving striations radiating from a central pit to a peripheral groove; superimposed individuals occasionally spiral in opposite directions. It is identical with the North American *Spirophyton* that characterises the Middle Devonian particularly and that is now recognised as produced by the burrowing worm *Taonurus*. For the present it can be said that

[1] Seward, *Ann. S.A. Mus.*, 1903, iv, 102; *Geol. Mag.*, 1909, 482; *Q.J.G.S.*, 1932, lxxxviii, 358. Schwarz, *Rec. Alb. Mus.*, 1906, i.

the age of the non-marine beds—about 4000 feet in thickness—preceding the Dwyka seems to embrace the whole time-interval from about the Middle Devonian to Lower Carboniferous.

D. The Cape System outside Africa

So extraordinary indeed are the resemblances—amounting almost to identity—of the Devono-Carboniferous successions in the Falkland Islands, Argentina, Uruguay, and southern Brazil, that a comparison therewith cannot be omitted.

Although the South Atlantic intervenes, the description just given of the Cape System applies almost word for word to the beds in the Falklands,[1] the three divisions in those islands being all but identical in their lithology, thickness (so far as can be judged), and fossils with those of the Cape, and being overlain by the Lafonian tillite, the undoubted equivalent of the Dwyka conglomerate.

In Argentina[2] the Sierra de la Ventana north of Bahia Blanca displays an isoclinally folded and inverted succession closely paralleling that between Oudtshoorn and Prince Albert :—from the ancient granite through the lower thick mass of fine-grained quartzites, through soft slates and fine-grained greywackés, with occasional Devonian fossils, coarse unfossiliferous greywackés, and a thick tillite followed by strata of lower Karroo age.

In Brazil,[3] in the State of Paraná and again in Uruguay, the Itararé glacials rest unconformably upon and overlap at either end a belt of flat-lying Devonian. The latter is made of white, false-bedded, gritty sandstones (Furnas) some 600 feet thick resting discordantly upon granite, etc., and repeating in detail the lithology of the Table Mountain Sandstone, and followed conformably by dark shales with an abundant " Bokkeveld " fauna. The succession is then terminated by the glacial formation, so that both stratigraphically and structurally this belt forms the direct counterpart to the area north-east of Clanwilliam, where the Dwyka transgresses across both the Bokkeveld and the Table Mountain Sandstone, which has, moreover, become distinctly thinner in this quarter. To the north-west of Paraná, in Goyaz, Matto Grosso, and in Bolivia a rather similar Devonian succession with a similar fauna is widespread.

Much farther to the west, in the pre-Cordillera of the Andes the Devonian appears to be mainly of a marine facies, being represented by

[1] T. G. Halle, *Bull. Geol. Inst. Upsala*, 1912, xi, 115; H. A. Baker, *Final Report Geol. Investigations in the Falkland Islands*, 1920-22.

[2] H. Keidel, *An. Minist. Agric. Rep. Argentina, Sec. Geol. Min.*, 1916, xi, 3; *Geol. Rundschau*, 1939, xxx, 148.

[3] J. Clarke, *Serviço. Geol. Min. Brasil*, 1913, Monogr. i.

dark greenish mudstones and greywackés only sparingly fossiliferous.

This wonderful lithological, palæontological, and structural parallelism between South Africa and eastern South America during this epoch cannot be sufficiently emphasised. Taken in conjunction with the evidence of a similar kind during the Permian and Triassic, it proves the intimate connection of these two continents over an enormous period of time.[1]

[1] A. L. du Toit, *Carnegie Institution*, 1927, Publ. 381.

CHAPTER XII

THE KARROO SYSTEM

Introduction. Facies. Subdivisions. Thickness. Cape-Transvaal Region. Dwyka. Ecca. Coal Measures. Stormberg. Lebombo-Buzi. Central Transvaal. Zoutpansberg. Waterberg. Bechuanaland. Tuli Trough. Middle and Lower Zambezi. Rhodesia. South-West Africa. Kaokoveld.

Introduction.—The early explorers were struck by the vast extent of the Karroo Region with its almost horizontal strata, and even today this feature impresses itself upon the traveller. For mile upon mile, extensively invaded by sheets and dykes of dolerite, can be observed a series of nearly flat-lying sandstones and shales of no small thickness within which fossil remains are scarce, represented only by the bones of animals, by a few plants, or by silicified wood, while marine shells are conspicuously absent.

Appropriately named the "Karroo Beds,"[1] this formation was found to cover much of what is now the Union, and subsequently parts of South-West Africa, Bechuanaland, and Rhodesia. Such relics indicate that by the beginning of the Mesozoic Era large parts of South Africa were covered by strata belonging to one or other of the divisions of this System, while the rest of the country stood at a higher level and contributed some of the sediments therefor. In addition those strata formerly extended far beyond the present confines of this land, the evidence suggesting that South Africa was at that time joined to South America, Madagascar, India, Australia, and Antarctica, and consequently formed only a part of a huge continent, called by Suess "Gondwanaland."

The total period involved ranges from the Upper Carboniferous to the Lower Jurassic, that is between 225 and 150 million years ago—which not only covers several of the recognised "systems" of Europe, but straddles the Palæozoic and Mesozoic Eras.

Discontinuity in Deposition.—Where first studied in the Cape and Natal, the base of this great succession is made by the thick Dwyka (Glacial) conglomerate, and the top by the basaltic lavas

[1] Also spelt "Karoo."

of the Stormberg and Drakensberg. Convenience demanded that the intervening beds—many thousands of feet in thickness—should be divided up, and the Ecca, Beaufort, and Stormberg Series were accordingly instituted, based in part upon lithological, in part upon palæontological grounds.

In the Transvaal and beyond a different and much thinner lithological facies appeared, which for long prevented closer correlation with the type-succession of the Cape. Not only is an abbreviated sequence the rule in the north, but *two stratigraphical breaks are usually present*, one near the base of the System and the other near the top. The overlapping of the higher zones is moreover so gradual that no obvious discordance can be detected, the true relationship of the groups becoming apparent only after proceeding a long distance.

Considering the enormous area involved, the presumable existence of distinct "basins" of deposition, the occurrence of inter-Karroo movements and therefore of overlaps, and the scarcity of fossils, it is a matter of congratulation that the strata of the various detached tracts within southern Africa can be so satisfactorily compared and correlated. See Fig. 40, in which the relative thickness of the subdivisions is indicated roughly, also their lithological characters by means of conventional stippling.

Southern and Northern "Facies."—This vast territory can, however, be divided by means of a very arbitrary line drawn from Windhoek to Belfast into *two main regions* characterised by rather different facies. Such a division is only very rough, there being actually a zone of transition over a hundred miles in breadth, due to the fact that the changes (in the facies) of the several subdivisions of the Karroo do not all take place upon the limit thus set, but at some distance either to the north or south thereof, and that gradually.

In the *Southern Area* (1) the formation and also its various subdivisions attain their greatest thickness; (2) the succession (except along its northern limit) is apparently an absolutely unbroken one, even passing down conformably into the Witteberg beds in the extreme south; and (3) the glacial (Dwyka) conglomerate is present at the base (except in the extreme north).

In the *Northern Area* (1) the succession is abbreviated and sometimes much reduced in thickness; (2) the glacial conglomerate is sporadically developed in the south, while unrepre-

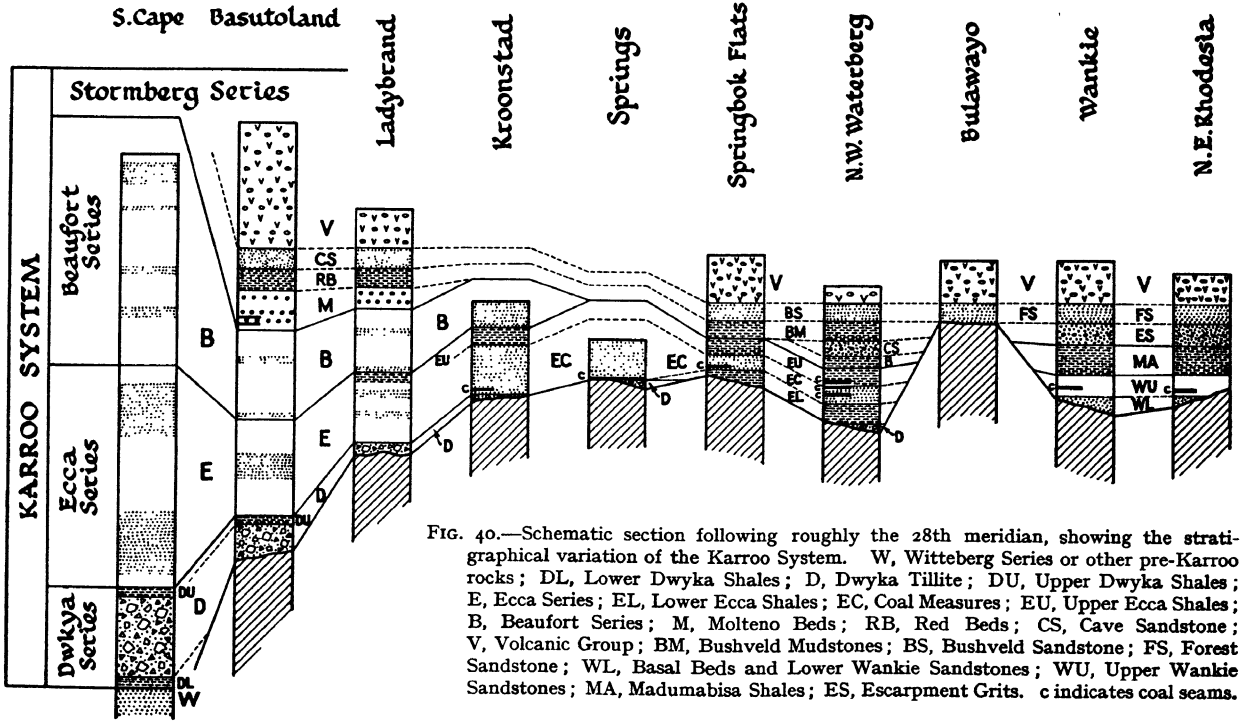


FIG. 40.—Schematic section following roughly the 28th meridian, showing the stratigraphical variation of the Karroo System. W, Witteberg Series or other pre-Karroo rocks; DL, Lower Dwyka Shales; D, Dwyka Tillite; DU, Upper Dwyka Shales; E, Ecca Series; EL, Lower Ecca Shales; EC, Coal Measures; EU, Upper Ecca Shales; B, Beaufort Series; M, Molteno Beds; RB, Red Beds; CS, Cave Sandstone; V, Volcanic Group; BM, Bushveld Mudstones; BS, Bushveld Sandstone; FS, Forest Sandstone; WL, Basal Beds and Lower Wankie Sandstones; WU, Upper Wankie Sandstones; MA, Madumabisa Shales; ES, Escarpment Grits. c indicates coal seams.

sented elsewhere, so that the succeeding strata (usually the Ecca beds) repose on the pre-Karroo floor; (3) the Ecca Series is different from that of the south and carries *coals*; and (4) a great *stratigraphical gap* occurs in the System, the upper part at least of the Beaufort Series is missing and the Stormberg Series rests on the Ecca beds or older rocks.[1]

Subdivisions.—Taking its nomenclature from the type-area of Cape-Natal, the System is subdivided into the four series as shown in the Table on p. 268, in which the *maximum thicknesses* are given in feet.

Thickness.—Excluding the Volcanic division, the maximum value of the System would have been attained only in the far south within the "*Karroo Geosyncline*," and it is unlikely that the figure of 35,000 feet, quoted above, is or ever was developed in any one locality, though probably approached in the Eastern Province and again in the Lower Shiré region of Nyasaland. Over the rest of the territory but rarely is a value of more than a few thousand feet exceeded.

Only from South-West Africa is evidence forthcoming of *marine* conditions having prevailed at any time during its deposition; on the contrary, nearly all the fossils known were undoubtedly *land or fresh-water forms*. The mode of accumulation of such a thickness of beds under such conditions and over so vast an area forms a fascinating study, to be dealt with in Chapter XXI.

A. The Cape-Natal-Free State-Southern Transvaal Region

(a) The Dwyka Series—*Introduction.*—The most striking of the subdivisions is undoubtedly the rock that for a long time proved a puzzle to geologists, called by such names as "trap-conglomerate" or "claystone-porphyry," and considered by some observers to be of sedimentary and by others of volcanic origin. The name "*Dwyka Conglomerate*" was introduced by Dunn from the occurrence of the formation on the Dwyka River near Prince Albert and is now known the world over, while its glacial origin is universally admitted. Colloquially, it is termed "*The Dwyka.*"

[1] See F. Dixey, *T.G.S.S.A.*, 1936, xxxviii, 73.

TABLE SHOWING CORRELATION OF "SOUTHERN" AND "NORTHERN" FACIES

SERIES		CAPE	Max. Thickness (Feet)	CENTRAL TRANSVAAL	Mean Thickness (Feet)	MIDDLE ZAMBEZI VALLEY	Mean Thickness (Feet)
Karroo System	Stormberg	Drakensberg Basalts	4500	Bushveld Amygdaloid	1000	Batoka Basalts	1000
		Cave Sandstone	1000	Bushveld Sandstone	300	Forest Sandstone	250
		Red Beds	1600	Bushveld Mudstones (Marls)	400	Escarpment Grits	550
		Molteno Beds	2000	~~~		~~~	
	Beaufort	Upper	2000	(absent)			
		Middle	1000				
		Lower	9000			Madumabisa Shales	900
	Ecca	Upper, Middle, Lower	10,000	Upper	300	Upper Wankie Sandstones	150
				Middle (Coal Measures)	200	Wankie Shales and Coals	120
				Lower	200	Basal Beds and Lower Wankie Sandstones	150
	Dwyka	Upper Shales	650	~~~		~~~	
		Boulder Beds (Tillite)	2500	Glacial conglomerate	0-30	(absent)	
		Lower Shales	750	~~~			
		Total	35,000	Total	2430	Total	3120

The wavy line indicates a disconformity or unconformity.

Historically,[1] it is sufficient to state that such a view was first suggested by Sutherland for the material in Natal so far back as 1868, and that three years later he announced that it was identical with the puzzling rock in the southern Karroo termed " trap-conglomerate " by A. G. Bain. The same conclusion was reached by Dunn in 1873 for the boulder-bearing rock in the northern Karroo, which much later he was able to prove continuous with the Dwyka conglomerate of the south, and he demonstrated the glacial origin for both northern and southern types. So far back, however, as 1876, Stow had in an unpublished work on Griqualand West not only recognised the antiquity of the glacial deposits in that quarter, but had deduced the direction of movement of the responsible ice-sheet. All the detailed investigation that has since been done has served to confirm the observations of these early workers and to show that only through the agency of an *ice sheet of continental dimensions* could the Dwyka " boulder-beds " have been formed. Moreover in India, Australia, South America, and elsewhere almost identical deposits have been discovered, in each case lying at the base of a thick series of strata with fossils identical with or closely allied to those of the Karroo System.

The use of the term " conglomerate " to describe the boulder-bearing material is not satisfactory since the inclusions are rarely abundant enough to bring the rock within the accepted definition of a "conglomerate." Also, it is too hard to be termed a "boulder-clay." The name " *tillite* " was accordingly suggested by Penck for application to a more or less indurated rock of this nature that had originally been a soft *till* or glacial boulder-clay.

Subdivisions.—The Series has been divided into the Upper Shales with the " White Band " at the top, the Boulder Beds, and the Lower Shales.[2] The latter are present only to the south of latitude 33°, the beds passing down *conformably* into the Witteberg Series; north of that parallel the tillite rests *unconformably* upon an undulating surface of pre-Karroo rocks.

In the south the thickness is almost 4000 feet, but the value diminishes in a northerly direction, while north of latitude 27° the formation becomes insignificant and erratically developed.

[1] The history of the controversy has been fully treated by G. S. Corstorphine, *S.A.A.A. S.*, 1904, 145.

[2] See editorial note on p. 259.

Distribution.—The Karroo beds in this region occupy a flattish basin, bounded on the south by the east-west system of the "Cape foldings," and the Dwyka tillite and the shales constituting the base crop out around its margins, except for a short distance in the south-east, where the formation passes beneath the ocean. In the Transvaal, however, the tillite is thin, is erratic owing to deposition upon an uneven surface, and tends moreover to be overlapped by the Ecca Series, so that the outcrops are often scanty and interrupted. To the north-west of the Cape Region lies another large tract, that of Gordonia and South-West Africa, with which the former was once connected.

In the south the beds have been repeatedly folded with the production of parallel or zig-zagging dark outcrops, the tillite displaying a conspicuous cleavage (Plate XXIII) and being harder than that in the northern Karroo. To the south of the main belt patches have been preserved in the Witteberg Series, as near Worcester.

Taken as a whole the various bands in the south compose a belt some 20 miles in width stretching from the mouth of the Great Fish River in the east to Karroo Poort in the west. Here the belt turns northwards, the dip flattens and the outcrop widens accordingly, so that from the Doorn River onwards through Bushmanland and past Prieska and Kimberley the Series covers a stretch of country from 30 to 60 miles in width, the tillite portion strewn with boulders while the Upper Shales make more diversified ground, owing to the presence of a rather constant series of dolerite sills following closely the horizon of the White Band. From Prieska north-eastwards the floor beneath the tillite becomes very uneven, so that ridges of the ancient rocks jut through the glacial covering, which continues to fill hollows and troughs in the former—the lower Harts Valley for example. Along the Vaal River up to Vereeniging the belt is probably narrow, while in Heidelberg, East Rand, Witbank, Middelburg, and Carolina, the glacial conglomerate makes a series of detached exposures but no continuous outcrop, but followed southwards through Piet Retief it thickens and again becomes of importance.

From Vryheid southwards the geological structure is, as mentioned earlier, a monocline, which by denudation has produced a double outcrop of this Series. That on the inland side slopes gradually westwards beneath the Ecca shales, its outcrop being highly irregular in plan owing to the dissected nature of

the country; the easterly one follows the coast very closely to Port St Johns, dipping seawards beneath the Ecca shales at angles of from 10° to 40°, but is frequently interrupted by faulting. The southernmost exposures are near the Umtata River mouth.

The Lower Shales extend along the base of the ranges made by the Witteberg quartzites, though often partly hidden by screes from the latter; but good sections can be seen at most of the " poorts " of the larger rivers, such as those of the Buffels south of Laingsburg or the Gamka.

Measured from the top of the uppermost thick Witteberg quartzite to the base of the tillite, they range from 400 to 900 feet in thickness with a perfectly conformable sequence, but north of Karroo Poort they thin out and so allow the boulder-bed to overlap on to the gently flexed Witteberg beds. Though consisting mainly of greenish and bluish shales and flagstones, they also include some hard greenish and greyish sandstones and quartzites. A break is also present at the Tygerberg near Prince Albert.

Indeterminable plant stems have been observed near Zoetendals Vlei, Willowmore, and impressions rather like *Phyllotheca*, as well as *Cyclodendron* and fish remains, on the Witteberg River south of Laingsburg. The beds represent sediments deposited in the body of fresh water into which the Dwyka ice-front subsequently moved and dropped its included debris. The change to the tillite is usually abrupt.

Although these strata have hitherto been grouped with the Dwyka Series, it is only proper to point out that lithologically they are more akin to the softer beds of the Witteberg Series, particularly those developed at the top of the latter, and that it would be more appropriate to include them in the Witteberg, thereby making the tillite the real base of the Karroo System, as is the case elsewhere.

The Boulder Bed.—That the tillite should have been regarded as a volcanic tuff or breccia is not altogether surprising, since its characters both in the field and in thin sections are often suggestive of a volcanic origin, more particularly as amygdaloidal diabase forms rather a high proportion of the inclusions and of the ground-up matrix. The rock is typically blue or greenish in colour, compact and fine-grained, and made up of small particles of sand and of various minerals embedded in a very fine-grained argillaceous matrix. In the latter are set pebbles and boulders of an immense variety of rocks, the majority of which can be

recognised as having been derived from the pre-Karroo formations —such as conglomerates, quartzites, sandstones, shales, slates, crystalline limestones, jaspers and banded ironstones, granites and gneisses, diabases and amygdaloidal lavas, quartz porphyries, serpentines, etc., the nature of the inclusions varying greatly in different localities.

The smallest fragments are commonly angular, but the larger ones all show a certain amount of rounding off at the corners. They range up to 10 feet across, though such sized blocks are exceptional, from 3 to 6 feet being frequently attained, large enough to indicate that running water could not have been the agent in their transportation over distances often amounting to hundreds of miles. These boulders are, as a rule, scattered irregularly through the matrix without any orientation; only in rare instances are they arranged in one or more well-defined layers. Plate XXI gives a good idea of the manner in which the inclusions usually occur. Striking nevertheless is the uniformity of the material, so different from any ordinary conglomerate, and this throughout an unbroken thickness sometimes of many hundreds of feet.

Not only is the great variety and size of the boulders remarkable, but a large proportion of them have scratched and striated surfaces (Plate XXII), while in many cases one or more striated flattened faces are present, giving a roughly facetted or "soled" form to the pebbles. In all respects these boulders are similar to the scratched "erratics" found in the moraines of modern glaciers and in the Pleistocene boulder-clays (tills) of Northern Europe and America. When, furthermore, it is observed that beneath the boulder-bed the rock-floor is polished and finely striated, the conclusion is inevitable that only moving ice can explain all the phenomena and that the *boulder-bed is therefore a very ancient moraine,* so that the employment of the term *tillite* to describe it is fully justified.

Throughout the southern outcrops the tillite is a hard blue rock generally breaking through pebbles and matrix alike, whereas the pebbles can easily be removed from the matrix in the case of the northern rock. In addition, a rough cleavage has been developed in the southern rock parallel to the strike of the formation, but at varying angles to its dip (Plate XXIII). This causes the tillite to weather into lenticular slabs or into sharp spikes, giving the hills a striking appearance; this slab-

Dwyka Tillite showing the irregular distribution of large and small inclusions through the sandy mudstone; two and a half miles west of Prieska.

[Face page 272

structure becomes weaker as the formation is traced northwards into the undisturbed region. A curious feature in both the northern and southern tillites, but more highly developed in the latter, is the regular and close jointing in the inclusions, the pebbles being often cut into a series of regular slices by fine joints.

Varieties of the Dwyka.—In addition to the normal blue or green unbedded tillite with irregularly scattered boulders, there are some other varieties which, although subordinate, are of use in indicating the conditions under which the formation was deposited.

For example, some of the material is distinctly stratified owing to the presence of layers much poorer in or devoid of inclusions, and at times having a more shaly matrix. Such "bedded Dwyka" may be found in the mass of the tillite, generally along definite horizons, indicating a break in the deposition of the "boulder-clay," but is more characteristic of the upper part of the formation, particularly in South-West Africa and the Vaal-Harts valley between Douglas and Vryburg, passing up into the type known as "*boulder-mudstone*" or "*boulder-shale*," an olive-coloured argillaceous rock through which are distributed erratically and often at wide intervals small inclusions of hard rocks only occasionally striated. A passage into pure shale is common, while the material may be impregnated with carbonate of lime, forming hard, brown-weathering bands, lenses, or concretions. These are obviously deposits laid down in still water—glacial muds into which boulders were dropped by floating ice. The folding of such sediments by floating ice has been recorded. Dyke-like tongues of coarser material in shaly stuff are ascribed to the sinking and melting of ice supercharged with rock waste.[1] Another intensely hard type, known as "*gravel Dwyka*" is composed of masses of small fragments of rocks, irregular in shape and rarely striated, cemented by calcareous matter. It may grade into sandstone with confused bedding, containing irregular bands and streaks of pebbles, a good example of which has a wide distribution in Zululand, forming a thick layer near the top of the formation. It is probably fluvioglacial in origin.

Phases of the Dwyka.—The available evidence indicates that over the bulk of the area occupied by the Dwyka the tillite was a "*ground moraine*," the product of immense continental ice-caps, and that after the melting of the latter the covering of morainic matter became

[1] G. Slater, *T.R.S.S.A.*, 1932, xx, 301.

buried beneath post-glacial silts—the Upper Dwyka Shales. In certain areas, however, the circumstances were somewhat different :—

(*a*) In the *Southern Karroo* the ice-front apparently discharged into fairly deep water in which a thickness of over two thousand feet of glacial matter accumulated. Occasional thin partings of shale indicate the cessation of ice-borne débris, brought about by the temporary retreat (in a northerly direction) of the ice-front. Certain bands of quartzite in the tillite can be compared with the so-called inter-glacial sands of the Pleistocene. Five distinct tillite zones are identifiable at Laingsburg. From Soetendalsvlei eastward to Barroe a band of exceptionally dark tillite lies below the main body and is parted from the latter by fissile shales and cross-bedded sandstones with combined thickness of up to 1000 feet (Rossouw).

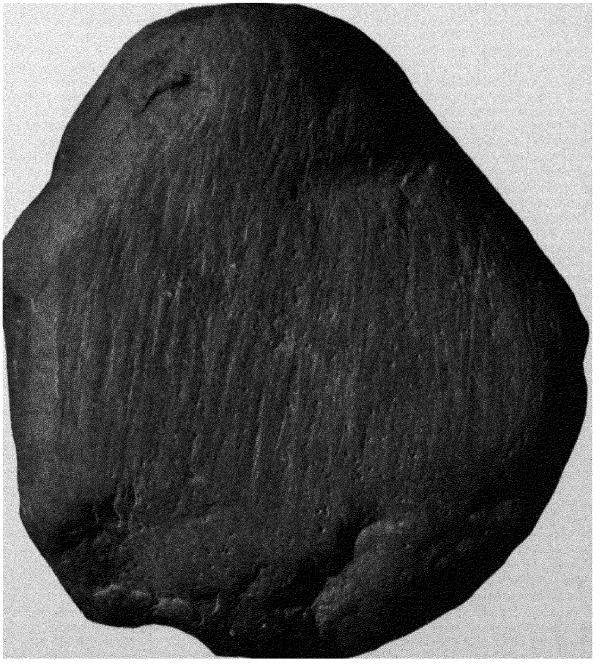
(*b*) Over the *Northern Karroo, Gordonia, and most of Natal and Zululand* the ground moraine was formed on low-lying land, which was gradually drowned as the ice-front retreated. Where the land stood highest the tillite was succeeded abruptly by shales, but where it formed low ground bodies of floating ice detached from the glaciers gave rise to deposits of boulder-shales. In South-West Africa indeed the latter were actually laid down in a *shallow sea.*

(*c*) Over the more elevated area lying just within the confines of the *Transvaal* the moraine-covered ground was seemingly exposed to the weather for a long period after the disappearance of the ice, not having been covered up until during Ecca times. The tillite is hence thin and irregular, having apparently been removed over certain tracts by " post-glacial " denudation and so, having been bleached by long exposure, possesses a pale bluish or greyish colour, quite different from that of the normal Dwyka. It is furthermore overlain, not by blue shales normally, but by conglomerates with pebbles derived from the tillite, grits, sandstones, and clays, sometimes difficult to distinguish from the glacial material. It seems that in most cases there is actually a disconformity present and that these younger beds should be grouped with the Middle Ecca " Coal Measures."

Thickness.—In the northern region, owing to the uneven nature of the floor, the tillite may in places be reduced to an insignificant stratum or may even be missing whereas close by it may fill hollows to depths of over a hundred feet. Its thickness increases generally southwards, so that in the Karroo Geosyncline 2000 feet have been measured at several spots, as at Grahamstown, and over 2500 feet at Laingsburg.

Just as in the case of the Pleistocene glaciation, the boulder-beds are poorly developed over the area from which the ice is presumed to have radiated.

1.—Glacial " Erratic " in Dwyka Tillite, Riverside, Prieska.



2.—Striated Boulder from the Dwyka Tillite.

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Striated Pavements.—It is highly probable that north of latitude 33° the undulating floor upon which the tillite rests has everywhere been polished and striated by the passage of the ice-sheet with its included débris. Exposures of such striated floors are, however, not frequent, because the surfaces are rapidly destroyed by weathering once the protecting tillite has been removed; more particularly is this the case with such rocks as granite, crystalline limestone, and slate, but search will often disclose a fringe of the polished and grooved floor showing from beneath its morainic covering (Plate XXIV).

Where the floor undulates a lot, rounded and striated hummocks frequently project through the mantle of Dwyka with their longer axes approximately parallel to the striæ crossing them, and often rougher and less deeply striated at one end than the other; such behaviour recalls the " crag and tail " or " stoss and lee " sides of the *roches moutonnées* that are to be met with in every region where ice has passed over hard rocks.

At Jackals Water in Prieska and at Vilets Kuil in Hopetown the *roches moutonnées* formed by the Kaaien quartzites and the Ventersdorp lavas respectively are very fine; the lee sides are on the south. Beautifully striated surfaces of lavas are to be found on the Vaal River near Pniel, Douglas and Riverton, of which a view is shown in Plate XXV, while others have been figured from around Balmoral and near Vryheid in the Transvaal out of a large number of occurrences; the surface exposed at the Umgeni quarries near Durban is apparently the original one observed by Sutherland in 1868.

While the striæ usually run in more or less parallel lines, cases are known where there are two sets of groovings, one crossing and partially obliterating the other, as in the Insuzi valley in Zululand, token of an invasion of the ground by a second ice-sheet advancing from a different quarter. " Plucking " can often be observed on the lee side, blocks having been started or rifted away from the hummock by the drag of the ice, while the morainic matter may occasionally have been squeezed into cracks and joints of the floor, as can be made out on the western side of the Great Karas Mountains in South-West Africa. " Chatter marks " are not uncommon.

In a few places, for example at Elands Vlei, near the confluence of the Tanqua and Doorn (Clanwilliam) rivers and at Riverton on the Vaal, a " boulder pavement " has been discovered in the midst of the tillite—that is to say, a flattish though furrowed surface belonging to the latter displaying a number of boulders pressed down flush with the

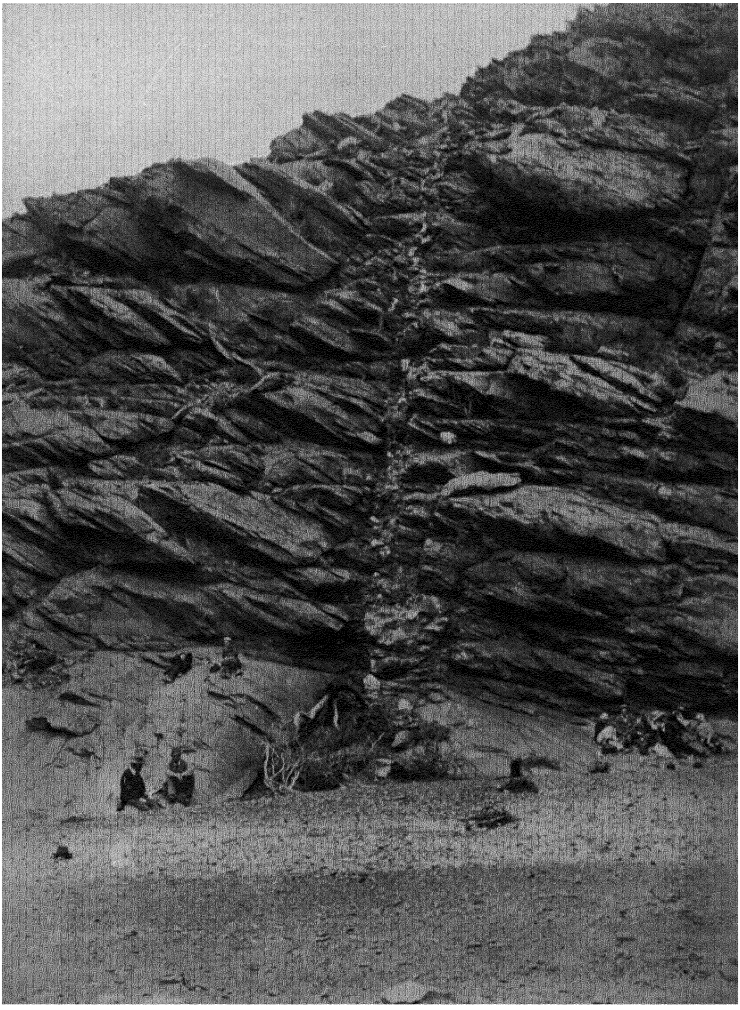
surface of the pavement and finely striated in a direction the same as that of the furrows. Such a surface was produced by the overriding of the previously deposited glacial material by the readvancing ice-sheet, which on melting laid down more " till." Similar cases are known from recently glaciated regions.

Over much of the country formerly occupied by the tillite the pre-glacial surface possessed a gentle relief, but in other parts the ground was highly irregular and the tillite consequently came to fill up steep-sided valleys; on the walls of the latter striations can in places be detected, and in rare instances fluted or undercut ledges. Great variations in level of the floor can sometimes be observed. The Doornberg chain rising about 1000 feet above the tillite at its base displays the outlines of a glaciated range; in Natal and in Zululand differences in level of 800 feet have been noted within a distance of a mile, while in a few cases the highest ground must still have projected from the tillite when the succeeding shales were being deposited.

The Direction of Ice-flow.—From isolated striated pavements, supplemented by the evidence of plucking, etc., it becomes possible to make out fairly closely the direction of ice-flow as well as the general course taken, from the presence of inclusions of distinctive types of rocks known to crop out along the path by which the ice could have travelled. Along with material of local derivation boulders can almost always be found referable to formations not represented near at hand and often only at a great distance off. Certain of these " erratics " must have been brought distances of at least 800 miles. Thus, inclusions of the Bushveld granite and of the Makwassi quartz porphyry are frequent in the tillite in Barkly West and Hopetown, while boulders of the Griquatown jaspers and of Matsap conglomerate are striking constituents of the Dwyka in South-West Africa and the western and south-western Karroo, though not anywhere to the south or south-east of Griqualand West.

By piecing together information of this kind it has been deduced that there were apparently several more or less independent *centres of glaciation*, exactly as was the case during the Pleistocene Ice Age of the Northern Hemisphere. The inferred movements of these bodies is shown in Fig. 41.

In the north-west the ice probably originated in the Windhoek Highlands (A), moving southwards into Namaqualand, probably farther. On the east it was overlapped by the Transvaal sheet (C), the largest of the bodies concerned, which radiated south-westwards across the entire Orange Free State, southern Cape, and northern Natal and



Dwyka Tillite standing nearly vertical and showing a band of boulders, Wittebergs River, Laingsburg. The largest boulder, near the base of the cliff, is 10 feet in diameter. The almost horizontal lines are joints; the inclined planes dipping from left to right are due to cleavage.

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Zululand, with a minor centre (B) coincident with the Griqualand West mountain land; while on the east there entered a sheet with origin situated far out in the present Indian Ocean (D), a body that was seemingly deflected southwards by the Transvaal Ice. Conjecturally the several masses merged in the south, passing into deep water in that direction, and consequently being buoyed up in the manner of the existing Barrier Ice of the Antarctic. During their forward movement the ice-sheets picked up material from the surfaces over which they

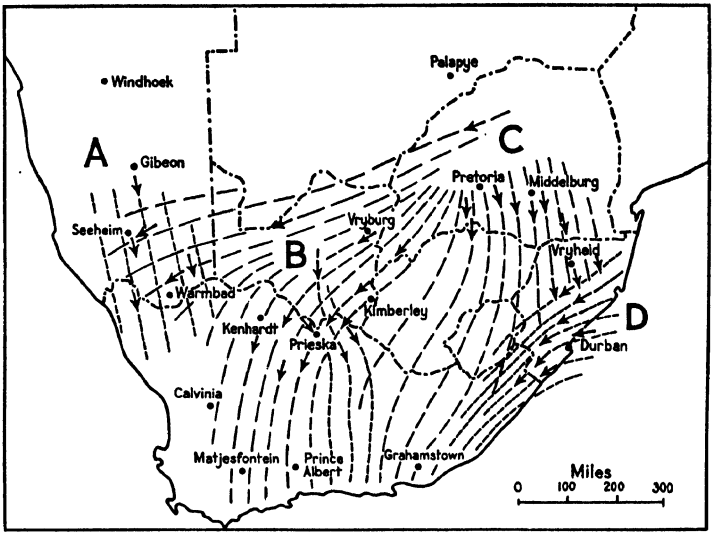


FIG. 41.—Showing the inferred Radiation of the Ice Sheets of the Carboniferous Epoch. The arrows indicate observed glacial striæ. A, Namaland; B, Griqualand West; C, Transvaal; and D, Natal Ice Centres.

were travelling, ground up much of it into mud, and on melting deposited morainic matter upon the scoured floor.

It is deduced that the Dwyka Ice composed the southern part of a vast cap that extended into Angola and towards the eastern Congo, where, to well north of the equator, valley glaciers descended from highlands with general northward movement and discharged into lakes.[1]

The Upper Shales.—Following on the tillite comes this group of shaly beds—from 300 to 700 feet thick generally, with greatest value in the south—predominantly olive-green in tint, but passing up into an important and conspicuous zone of black carbonaceous

[1] A. C. Veatch, *Geol. Soc. Amer.*, 1935, Mem. 3; N. Boutakoff, *XVII Inter. Geol. Congr.* (1937), 1940, 6, 223.

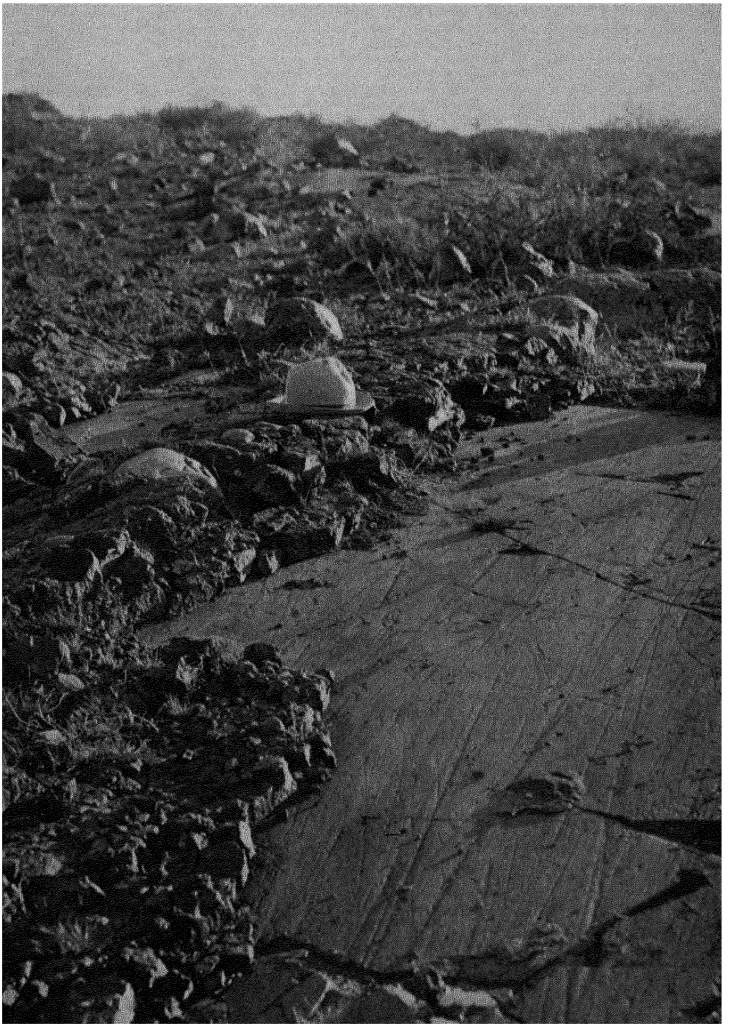
shales, which weathers white on exposure and is accordingly known as the "*White Band.*" At its top in the western and southern Karroo, and ultimately near the Umtata River mouth, appears the thin but persistent layer of white-weathering grey *chert* that serves as the arbitrary boundary between the Dwyka and Ecca series. In the northern Karroo and beyond, this band is absent, but cherty concretions are sometimes present.

In the south the passage from the tillite is sometimes sharp, in other places gradual, but in the north it is often difficult to draw a divisional line owing to the presence of bedded glacial material, boulder-shale, etc. To the north-east an overlapping takes place, so that only traces of the carbonaceous zone mark out this group, while in Natal the latter is missing and the tillite is directly overlain by the Lower Ecca Shales and to the north of Piet Retief by the Middle Ecca "Coal Measures"; presumably between Kimberley and Vereeniging a corresponding change takes place.

Near their base the shales carry occasional hard, black, fine-grained phosphatic nodules that have yielded remains of palæoniscid fishes and tree stems. Dark flagstones, thin sandstones, and shales appear higher up accompanied by highly ferruginous bands and by lenses and concretionary masses of dolomitic limestone, often veined by quartz, above which come the carbonaceous shales of the White Band, some 50 to 100 feet thick in the southern Karroo and about half that in the northern.

Prospecting pits sunk in this band around the margin of the Karroo prove that the shales may contain as much as from 12 to 14 per cent. of carbonaceous matter including some hydrocarbons, so as even to be able—as at Orange River Station—to yield some oil upon distillation; but no high grade oil-shale or coal has yet been discovered therein. They contain in addition a little carbonate of lime, often in nodules, and a fair amount of pyrite, these two minerals along with the carbonaceous matter reacting under the influence of air and moisture leaving the shales white or pinkish with the laminæ much contorted and yielding hydrated iron oxide (ochre) and sulphate of lime (gypsum) in glistening crystals in the soil. Where the vegetation is not abundant, the pale outcrop is commonly conspicuous from afar (Plate XXVI).

The sediments composing the White Band were apparently in the nature of black, organic highly sulphuretted muds like those forming in the Black Sea or in the Gulf of Bothnia at the



Dwyka Tillite resting on striated floor of Diabase, Nooitgedacht, near Riverton, Kimberley district.

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present day, and were probably laid down in the deep waters of an estuary, a view supported by the occasional remains of fishes, crustacea, and the free-swimming little reptile *Mesosaurus*. It is of particular interest that an identical carbonaceous band carrying *Mesosaurus*—the Iratí (Iraty) Shales—should be equally widespread in southern Brazil.

Fossils.—Chief among the scanty evidences of life comes *Mesosaurus*—the zone-fossil of this group—(Fig. 49), occurring as impressions left in the white shale by the removal under weathering of the fragile bones; specimens have been obtained from the districts of Kimberley, Herbert, southern Bushmanland, Calvinia, Keetmanshoop, and the Kaokoveld. The marine incursion in South-West Africa is marked by a few mollusca, of which the curious thick-shelled lamellibranch genus *Eurydesma* is of assistance in the correlation with India and Australia, while palæoniscid fishes are also represented. Fish scales occur in black shales underlying the Matsap Pan, Griqualand West.

Though it would hardly be expected that the tillite should contain fossils, *Gangamopteris* has actually been found jammed in between the boulder-bed and the glaciated floor near Strydenburg, north of Britstown, while at Vereeniging well-preserved fronds were discovered by Leslie in a shaly layer in similar position right against the Dolomite. These are important finds, since they show that the Glossopteris Flora was already flourishing in South Africa while glacial conditions held sway. Both the tillite and the overlying shales from Vereeniging have on maceration yielded winged spores.

The following are the records to date :—

White Band—Plants	.	*Glossopteris* sp., Kimberley.
Fishes	.	*Palæoniscus capensis* Broom,[1] Calvinia.
Crustacea	.	*Notocaris* (*Pygocephalus*)[2] *tapscotti* Broom, Kimberley, and *Anthrapalæmon* sp., Orange River Station.
Reptilia	.	*Mesosaurus tenuidens* Gervais[3]; *M. pleurogaster* Seeley[4]; *M. capensis* (Gürich)[5] (see below).

[1] R. Broom, *Ann. S.A. Mus.*, xii, pt. 1.

[2] H. Woods, *T.G.S.S.A.*, 1922, xxv, 41; R. Broom, *Proc. Zool. Soc.*, 1931, 571.

[3] P. Gervais, *Description du Mesosaurus tenuidens*, Montpellier, 1865.

[4] H. Seeley, *Q.J.G.S.*, 1892, xlviii, 586.

[5] R. Broom, *T.S.A. P. S.*, 1904, xv, 103; *Ann. S.A. Mus.*, 1908, iv, pt. 8. Huene has combined these three forms in the single species *M. tenuidens*.

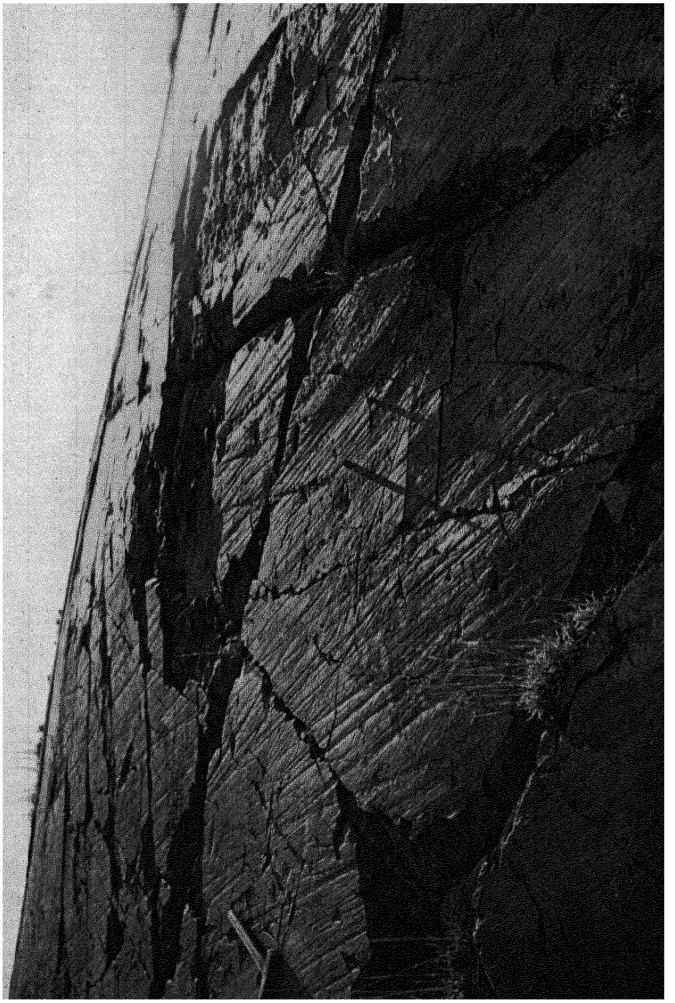
Upper Shales and Boulder Mudstones—Plants	.	*Lepidodendron australe*[1] M'Coy, Orange River Station.
,,	.	*Dadoxylon* sp., Keetmanshoop and Gordonia.
Mollusca	.	*Eurydesma globosum*[2] Dana, Keetmanshoop.
,,	.	*Orthoceras* sp., Keetmanshoop.
,,	.	*Conularia* sp., Keetmanshoop.
,,	.	*Aphanaia haibensis* Reed,[3] Warmbad.
Echinoids		*Archæocidaris* sp.,[4] Keetmanshoop.
Fishes	.	*Acrolepis lotzi* Gürich,[5] *Namaichthys schrœderi* Gürich, *Rhadinichthys* (?) and *Elonichthys* (?), all Keetmanshoop.
Boulder-Bed—Plants	.	*Gangamopteris cyclopteroides* Feist.,[6] Vereeniging.
Lower Shales—Plants	.	*Phyllotheca* (?), *Cyclodendron*, fishes.

The age of the Dwyka Series will be discussed later, so that it will be sufficient to remark that the evidence all points to a correlation of the Glacials with the *Upper Carboniferous* and the succeeding Shales with the *Lowest Permian*.

(b) The Ecca Series

Historical.—Following conformably upon the Upper Dwyka Shales in the Cape comes the group of shales and sandstones named the *Ecca Beds* by Rubidge from its occurrence in the Ecca Pass north-east of Grahamstown. Never clearly defined by him, its base was fixed in 1896 at the highest chert band of the Dwyka Shales. In Natal, however, the term " Ecca " had been bestowed—though correctly it would seem—upon the strata that immediately succeeded the Dwyka tillite. The upward limit remained undefined since no clear line of demarcation from the overlying reptilian-bearing strata, styled the Beaufort Beds, was apparent. It was, moreover, not until 1918 that the Transvaal " Coal Measures " were found to form the *middle portion of the Series*.[7]

[1] A. C. Seward, *Geol. Mag.*, 1907, 484 (specific identification doubtful).
[2] H. Schroeder, *Jahr. Geol. Land*, Berlin, 1908, xxix, 694.
[3] F. R. C. Reed, *T.R.S.S.A.*, 1935, xxiii, 161.
[4] S. H. Haughton and H. F. Frommurze, *T.G.S.S.A.*, 1928, xxx, 141.
[5] G. Gürich, *Beitr. Geol. Erfor. Deut. Schutz.*, 1923, xix, 26.
[6] T. N. Leslie, *P.G.S.S.A.*, 1922, xxiv, p. xix ; *Ann. Rep. G.C. for* 1907, 182.
[7] A. L. du Toit, *P.G.S.S.A.*, 1918, xxi, p. xvii.



Glaciated floor of Diabase (*Roche moutonnée*), Nooitgedacht, near Riverton, Kimberley district.

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It has become apparent that the formation is built of *four distinct though overlapping and interfingering phases* derived from separate sources. These are A, *the Southern or Green Ecca* of the Cape to the south of lat. 32°; B, *the Central or Blue Ecca* of the Keetmanshoop-northern Karroo-Pondoland region; C, *the Coal Measure Ecca* of the north-east—Natal, Transvaal, northern Free State, eastern Bechuanaland and Rhodesia; and D, *the Red Ecca* of South-West Africa. Their common boundaries are of course transitional.

Within the Great Karroo Basin the first three contributors crop out in a ring, from 10 to 50 miles wide usually, inside that of the Dwyka, running from Peddie in the south-east past Prince Albert, Karroo Poort, Calvinia, Britstown, Hoopstad, southern Transvaal and down the centre of Natal to the Umtata River, dipping inwards beneath the central mass of higher strata. In the extreme south-west a tract 30 miles long has been faulted down between Worcester and Robertson.

A. *The Southern or Green Ecca Phase*

Deposited within the Karroo Geosyncline, these strata were involved in the Cape Folding and are in places tilted up to the vertical or even slightly overturned towards the north, as between Prince Albert and Klipplaat. Their thickness is great, from 6400 to 7000 feet having been measured by the Geological Survey about Prince Albert and from 9000 to 10,000 feet at Miller and Wolwefontein stations (Rossouw) and over 10,000 feet at Committees Drift on the Great Fish River (Mountain).[1]

From the thinning out of the sandstone groups to the north, the directions of current bedding, etc., the bulk of the sediments must have been derived from the south and south-east and deposited in shallow water, perhaps in part as broad alluvial fans over the southern side of the "basin." A three-fold sub-division is possible into :—(*a*) Lower Shales and Sandstones (Plate XXVII), a group which becomes dominantly arenaceous eastwards; (*b*) Middle Shales, bluish with minor sandstones, up to 4700 feet thick east of Klipplaat, and which becomes black and carbonaceous about Grahamstown,[2] and (*c*) Upper Sandstones with mudstones and shales, becoming argillaceous towards the top.

[1] E. D. Mountain, *P.G.S.S.A.*, 1946, xlviii, p. xxiii; *Union S.A.G.S.*, 1946, Expln. Sheet 136.

[2] *Ibid.*

The sandstones are grey to green and often dark and massive, with spheroidal weathering, thereby resembling igneous rocks. The softer beds are green or olive to mauve argillaceous flagstones and mudstones with nodules or lenses of limestone and thin sandstones on various horizons. Local unconformities and confused bedding are often present, sometimes sandstone veins. Silicified wood is common, while fronds of *Gangamopteris* and *Glossopteris* have now and again been found.

The boundary with the Beaufort has been drawn where the first red and purple mudstones appear in some quantity.

B. *The Central or Blue Ecca Phase*

This presumably deeper water assemblage, 2000-2500 feet thick, laid down along the north of the Karroo Geosyncline, consists almost wholly of bluish to greenish shales with some thin flaggy layers and deep brown-weathering calcareous concretions and lenses. Ripple-marking is common. While silicified wood—probably *Dadoxylon*—is fairly frequent, no recognisable plant remains have been found, though indistinct curving fucoid-like markings are abundant. Flagstones from the Zak (Sak) River and elsewhere have yielded prints of small four-toed creatures and trails of fishes, crustaceans and insects.

In the Klein Roggeveld south of Calvinia the Series swells to over 3500 feet, due to wedges of fine-grained greenish mottled sandstone entering from the south and belonging to the Southern Facies, while some of the softer strata are purplish.

In Pondoland the shales are dark blue—bleaching to yellow—with calcareous and sometimes pyritic concretions and fucoid-like markings, but unfossiliferous. Here again the sandstone facies of the Middle Ecca enters at about the Umtamvuna River and becomes progressively thicker northwards (p. 284).

The boundary with the Beaufort beds is readily drawn where sandstone horizons make their appearance.

C. *The North-eastern Coal Measure Ecca Phase*

(*a*) The belt made by the now triply divided Series runs regularly through Harding, Ixopo, Maritzburg, to Greytown, widens over northern Natal and Zululand and then expands over the Transvaal " Highveld " to join with the broad belt belonging

Outcrop of White Band near Floris Kraal, Laingsburg, showing dark shales of the Dwyka passing beneath the white-weathering shales and these underlying the zone carrying the thin white chert horizon, forming the crest of the ridge. Ecca Beds cap the hill in the distance.

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to the western Free State. In the Transvaal section dolerite sills become less abundant.

With the progressive rise of the base from the Tugela northwards the undulating floor of older rocks projects through the Karroo covering at many places, as between Middelburg and Heidelberg. North of Belfast outliers reach an altitude of about 6500 feet. The down-warped extension of the Series over the central Transvaal is referred to later.

(*b*) Brought down to sea-level by the monocline traversing Natal, the Series, following regularly upon the Dwyka tillite, reappears along the coast, though continuity in the belt is broken at a number of points by fractures oblique to the shore-line. The dip as a whole is seawards at angles of from 12 to 30 degrees, the strata being abundantly injected with dolerite; but at Port Shepstone and again in the Umlalazi Coalfield the structure is that of a basin faulted down against the granite on its north-western side. The Beaufort beds are preserved only in the trough-faulted strip of the Umhlatuzi Valley (see later).

(1) THE LOWER ECCA SHALES.—These rest evenly and usually sharply upon the tillite and consist of unfossiliferous dark blue or green fissile shales with some flagstones and occasional concretions and lenses of impure limestone or clayband ironstone.

In Alfred County their thickness is 1400 feet, at Greytown 1000 feet, a little north of the Tugela 500 feet, after which they thin rapidly over the Nqutu and Vryheid districts; northwards from the Pongola River their occurrence is sporadic, while through Ermelo and beyond this argillaceous zone is absent and the "Coal Measures" come to rest either upon the Glacial conglomerate or directly upon one of the ancient rock systems. Borings in the Odendaalsrus area prove these to be present in their proper position, indicating an overlapping like that in the east.

(2) THE MIDDLE ECCA OR COAL MEASURES.—The term "Coal Measures" has passed into such general use in Natal and the Transvaal that it would now be difficult to substitute an equally appropriate but less committal title. One should note that this division is not the sole one in South Africa carrying coal seams and that it is not equivalent to the "Coal Measures" of the Carboniferous Epoch, being of later age, namely *Lower Permian.*

Distribution.—Characterised by thick bands of sandstone and grit alternating with softer layers, and contrasting therefore with

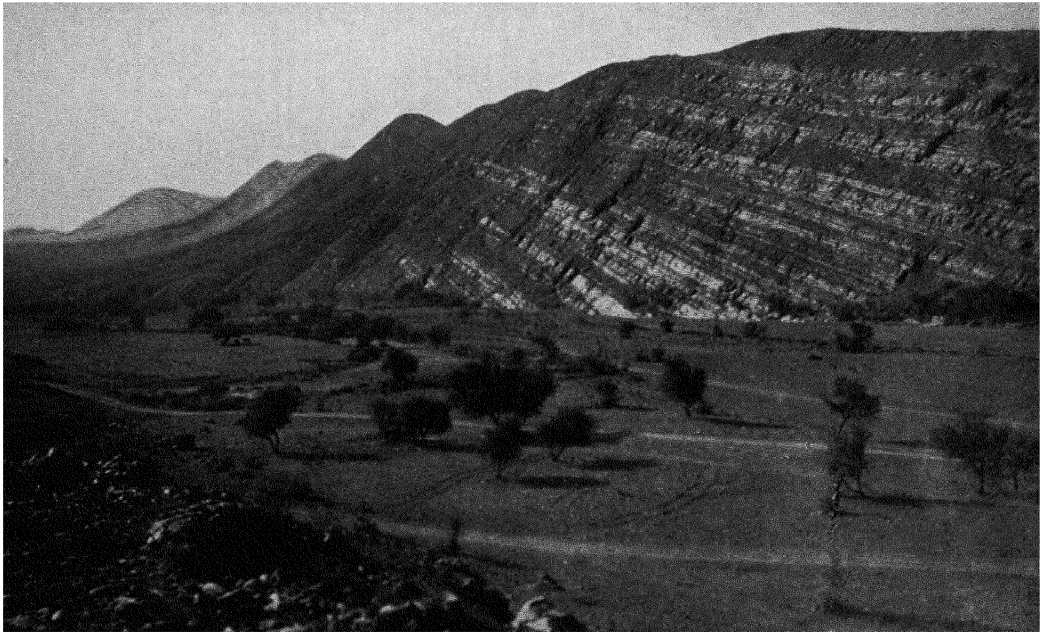
the shale groups above and below, this is naturally the dominant member of the Ecca and almost its sole representative in the north and north-west, consequently the remarks made above as to the distribution of the Series itself will apply practically to this division.

In Natal the sandstones, aided by horizontal sheets of dolerite, make the escarpment behind Umzimkulu and Byrnetown, build the Town Hill at Maritzburg and its continuation in the Blinkwater Mountain to Greytown. Here, very much thicker, the group spreads westwards up the Tugela Valley and northwards into Zululand, occupying much-dissected country in which these strata build great spurs and tabular masses such as Mont Allard, Umsinga, Qudeni, Elandsberg, Hlobane, Dumbe, etc. Farther to the north the terraces become lower and the rolling high-veld is reached with occasional ledges of sandstones.

Along the Natal coast the group is represented at Port Shepstone, Umgababa, beneath the Bluff at Durban, from the Umgeni onwards to Stanger (including the Umhlali Coalfield) and in the Umlalazi Coalfield in Zululand. As remarked earlier, this group rests conformably upon the Lower Shales in the south, but to the north-west of a line drawn from Kroonstad to Piet Retief upon either the glacial conglomerate or the old and often highly uneven pre-Karroo floor, a fact that has an important bearing on the persistence of the bottom coal-seams. There is good reason for believing that the progressive overlapping is such that *frequently the lower part of the Coal Measures must be missing* in the broad concealed region between Ladysmith and Kimberley, confirmed by a deep boring near Kestell.

Lithology.—Considering the size of the area concerned and the fact that the formation is developed in the central and northern Transvaal as well, its lithological uniformity is striking. In the broken country of the south and east the sandstones commonly make cliffs or ledges beneath which the softer strata are often well exposed, but in the gently undulating region to the north and west the beds have broken down to form a deep sandy or loamy soil and the outcrops are restricted to those of the harder rocks, so that evidence respecting the nature of the softer strata has largely to be obtained from borehole records.

The sandstones are yellowish to whitish in outcrop and frequently coarse in grain, passing into massive grits with subangular to irregular grains and small pebbles. Feldspar is a common constituent; coarse arkosic beds carrying fresh angular



Tilted Ecca Beds, Buffels River, Laingsburg. Basal shaly division on left, middle arenaceous division on right.

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feldspar—mostly orthoclase and microcline—are common in Natal, and indicate a granitic or gneissic origin for the material. The grits carry occasional washes of small pebbles, principally vein quartz or quartzite, while now and again conglomerates are to be found at or shortly above the base of the group, *e.g.* Heidelberg, Witbank, Vereeniging, being better developed in the northern quarter, where the inclusions could have been furnished by the older formations or by the denudation of the glacial conglomerate. Characteristic are the pitted surfaces produced under weathering, blocks having sometimes been hollowed out in the most curious fashion (Fig. 42) while the crust has suffered

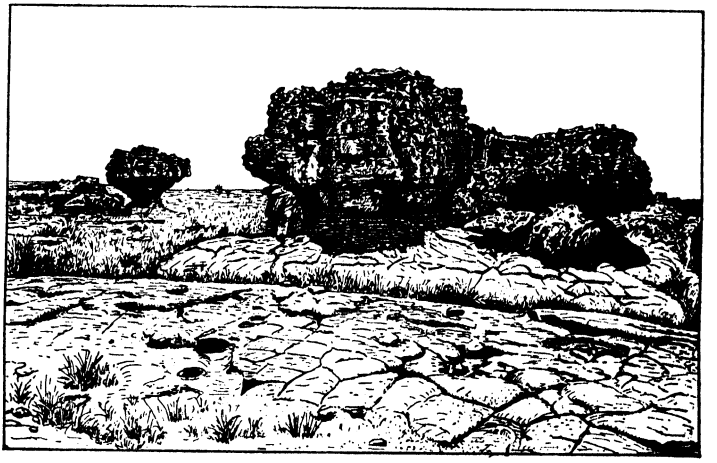


FIG. 42.—Coal Measure Grits showing the characteristic mode of weathering. (*After* Mellor.)

induration by the deposition of silica between the sand-grains. False-bedding is almost universal; in Natal the planes commonly dip west or south-west suggesting that the source of the detritus was situated to the east of Zululand.

The finer sandstones are generally white, and alternate with or grade into laminated micaceous flagstones and sandy shales in which casts of worm burrows are common. A lot of the so-called "shale" is really very sandy, but the abundance of mica causes the rock to split along the bedding-planes. A grey, dark brownish or blackish colour is the rule, while carbonaceous zones are common; pale blue, green, or red tints are generally

absent. In the Natal Coalfield the strata near the top of the group include a high proportion of dark shales with a few bands of brown-weathering calcareous grit or impure limestone ; between Dundee and Ladysmith oval ferruginous concretions carrying fish remains are rather abundant in a thin zone in the shales. Stratified iron-ores up to a few feet in thickness have been found in a few localities, mainly in Natal, though also in the Witbank area. The plant fossils are referred to in Chapter XIII. Fireclays are represented at Boksburg and at Olifantsfontein near Pretoria at the base of the Series.

Thickness.—In the south of Natal the figure is under 300 feet, at Maritzburg 600 feet, near Greytown 1000 feet, with maximum of 1700 feet at Impofana, thinning to north and west, to 1300 feet at Vryheid, 1100 feet at Dundee, over 400 feet at Witbank, under 200 feet in the Springbok Flats and about 60 feet at Odendaalsrus.

The Coals and their Origin.[1]—The conditions under which the group was laid down were eminently favourable both for the growth of vegetation and the formation of coal, with the result that the reserves of that mineral in the Union are of enormous magnitude (see p. 502), for although the seams in each of the fields are few in number, their individual thicknesses are often remarkable—from 10 to 20 feet being not unusual in the Transvaal. Furthermore, boring during recent years has been demonstrating the great lateral extension of individual seams, though it remains certain that the lowest one is commonly limited through abutting against low ridges of the older rocks.

The majority possess *sandstone floors*, are more homogeneous and purer in their basal parts, become intermingled with shaly coal or shale higher up and are overlain by dark shales and thin sandstones, while as in other parts of the world splitting of the seams is sometimes to be found. Practically all the coals—and the torbanites as well—are restricted to a limited zone, normally located a little above half-way up in the succession, but, owing to the progressive disappearance of the lower beds in a north-westerly direction, the seams are found only a little above or right at the base of the Series within the region extending from

[1] E. T. Mellor, *G.S.Tvl.*, Mem. 2, 1906. A very useful discussion embodying more recent data will be found in W. Wybergh's Memoir, *Union S.A.G.S.*, 19, i, 1922 ; ii, 1925 ; iii, 1928. A. C. Graham and P. N. Lategan, *The Coals of the Witbank District*, 1931.

Bothaville to Belfast. Serious from the economic standpoint has been the alteration of the coal with the development of *anthracitic characters* through the proximity of intrusive dolerite, most particularly in Natal.

Their mode of origin has been carefully studied by Mellor in the Witbank district, the facts supporting generally the view that they were formed by the growth of vegetation *in situ*. Here the ancient land surface bordering the wide swampy flats was right at hand or lay not far to the north, and it is deduced that the vegetable growth extended out over this marshy ground somewhat as in the case of a peat-moss, and so gave rise to the seam. Despite the variability in the character of the strata above or below, the coal-seams themselves are remarkably uniform as regards thickness and quality over areas of sometimes hundreds of square miles. Only near the ancient ridges do the coals show rapid variation, so that sections even near together may be entirely different. The basal seam at Witbank includes in places boulders from the nearby tillite. It has furthermore been observed that, whereas the lower parts of the seams are usually the purer, shale bands generally make their appearance towards the top, pointing to repeated inundation of the swamp by waters carrying mud in suspension, after which the area became temporarily overwhelmed by sands and clays. Evidence has been obtained in more than one place pointing to the replacement of the coal by gritty material, apparently through the filling in with sediment of a drainage channel traversing the surface of the swamp.

Commercial *fireclays* are present at Boksburg, Lawley and Olifanstfontein in the Transvaal, reposing on resorted tillite and, in one case at least, on impure coal. Of kaolinitic composition, they contain little colloidal matter and seem to have been largely derived from rock-flour. Although no true "underclays" or "seat-earths" are present, such as are found in the European Carboniferous, some hard "seat-stones" devoid of bedding have been recorded, *e.g.* the Douglas Colliery, Witbank, while root markings have been preserved elsewhere in the rock immediately beneath the coal, for instance around the boulders in a floor of glacial conglomerate, as at Boksburg. Absolute confirmation of these views is afforded by the unique "fossil forest" at Vereeniging, where the casts of the stumps of trees actually rooted in the upper surface of the coal were temporarily exposed in the bed of the Vaal River over an area of two acres (Fig. 43), accom-

panied by prostrate stems some of which attained a length of 40 or 50 feet without showing much diminution in breadth and that belonged to trunks fully 2 feet in diameter—probably *Cordaites*. The standing forest growing on the thick vegetable accumulation then became submerged and its remains buried beneath sand and mud.[1] Such alternating conditions, varying in their duration and intensity, were undoubtedly repeated a number of times during the history of our Coal Measures.

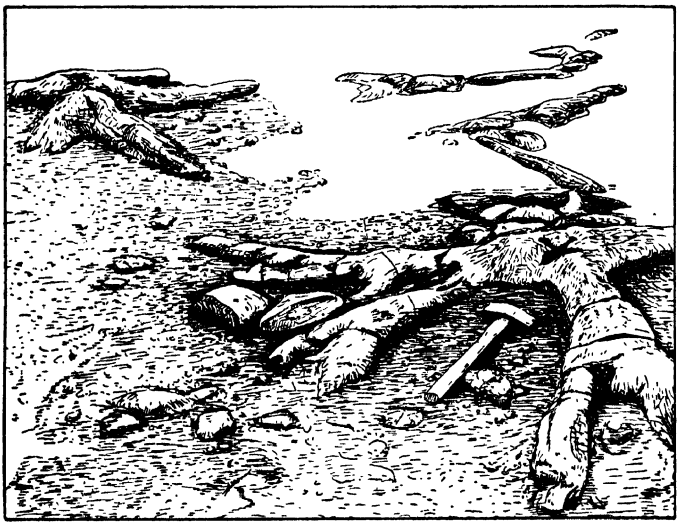


FIG. 43.—Two Stumps with Roots of Fossil Trees, bed of Vaal River, Vereeniging. (*After* Mellor and Leslie.)

There is no reason to doubt that rather similar conditions prevailed in the other coalfields of the Transvaal and Natal, though on the contrary the slightly later coals of the northern Transvaal and of Rhodesia seem to have been largely formed out of drifted vegetable matter.

Under the microscope they show a considerable variety in composition and structure, though little has been written about them. The more bituminous kinds and those composing the brighter bands consist of brownish material, largely "vitrain," representing decomposed and partly disintegrated vegetable matter, showing remnants of the cell structure of the woody

[1] E. T. Mellor and T. N. Leslie, *T.G.S.S.A.*, 1906, ix, 125.

tissues and sometimes evidences in the latter of the micro-organisms of decay; films and streaks of opaque muddy matter are common, which help to account for the high percentage of ash. The base of the main seam at Witbank contains recognisable spores, while the broad bright bands higher up represent the flattened stems of trees, implying a period of forest growth. Curious is the absence, according to P. E. Hall, of dull granular " durain " from some of the Witbank coals.

That the climate was not only *wet but cold* is suggested by palæogeographical evidence, the recent disappearance of glacial conditions, the absence of fireclays of lateritic composition beneath the seams, the presence of fossil wood showing annual rings, and perhaps by the abundance of fresh angular feldspar in the associated grits.

The *Torbanites* or so-called " Oil-shales " of the Ermelo and Wakkerstroom districts are closely associated with the coals, forming sometimes a member of a compound seam of coal and shale. The fact that a torbanite may pass upwards or downwards by means of lower grade material—carrying quartz grains and laminated through the presence of mica—into either barren shale or soft sandstone suggests deposition in still water, wherein dark muds charged with " sapropelic " matter could accumulate. Thin sections show elongated or flattened resinous-looking bodies set in an opaque groundmass, also some irregular grains of quartz, perhaps wind-borne particles (see p. 534).

(3) THE UPPER ECCA BEDS.—Being a thin zone—800 feet thick in the south and 500 feet in the extreme north—this sub-division makes a narrow and indented outcrop that stretches from the base of the Ingeli Mountain past Creighton, Howick, Weenen, Ladysmith to Volksrust. Here they spread westwards over the lower ground about Wakkerstroom and extend past Heilbron to the Voorspoed Diamond Mine and then to the south-west, having been cut in boreholes at Kroonstad and Odendaalsrus. They are again represented far to the north in the Springbok Flats and beyond.

These soft blue shales are only distinguishable from the Lower Ecca beds through carrying hard greyish concretionary nodules, lenses or impersistent layers fairly rich in *phosphate of lime*, abundantly exposed in the gully-seamed country about Ladysmith or Weenen.

Almost the sole fossils are scales of fish in some of the nodules, that

have been referred to *Acrolepis molyneuxi* and *A.* cf. *digitata*,[1] and some *Dadoxylon* wood from Weenen that has also been phosphatised, carrying up to 40 per cent. of phosphoric acid.[2]

(c) The Beaufort Series

Historical.—It was the discovery of the amazing reptilian remains in the Karroo by A. G. Bain in 1856 that made this formation famous in the geological world. To him was due the name " Fort Beaufort Grit," but in 1867 Rupert Jones introduced the title " Beaufort Beds " for the reptilian-bearing strata both at Beaufort West and Fort Beaufort instead of Wyley's " Reptilian Beds."

Their lithological and palæontological subdivision was effected at a much later date.

Distribution.—Following the Ecca conformably—and indeed never clearly defined from the latter by any of the earlier geologists—the Series makes a huge oval extending from the Tanqua Karroo to Wakkerstroom and from East London across to De Aar, an area some 800 miles in length by 300 in breadth, transected on the south-east for a relatively short distance by the Indian Ocean. The structure, conforming precisely with that of the underlying Ecca, is a very shallow basin with its southern margin determined by foldings, though dips are moderate therein, except in the section north of Prince Albert. Resting in turn upon the Beaufort beds in the north-eastern half of the basin is the great cake of Stormberg beds constituting Basutoland and the adjoining highlands.

Affected by the Natal monocline, the entire succession is bent over just south of Port St Johns so as to dip eastwards; while to the north of that place, dropped down between faults, the beds are inclined seawards at angles of up to 60°. The continuation of this flexure brings down the formation again far to the north in eastern Zululand.

Ubiquitous is the intrusive dolerite, the strata, excepting in the folded region of the south between the Klein Roggeveld and Somerset East, being intersected by legions of sills and dykes (Fig. 44).

[1] F. H. Hatch, *Ann. Natal Mus.*, 1910, ii, 227.
[2] E. Warren, *Ann. Natal Mus.*, 1912, ii, 356.

Thickness.—Owing to the great breadth of outcrop, the low dip and the abundance of dolerite, it is difficult to obtain satisfactory estimates for the thickness; but the Series is enormously developed in the south towards the Geosyncline, 8000 feet having been measured in Pondoland and 9000 feet for only its lower part east of Jansenville and east of Peddie. It falls off in a northerly and north-easterly direction to 3800 feet at Bulwer and 2200 feet between Newcastle and Harrismith, though exceeding 2200 feet in the eastern part of the Orange Free State.

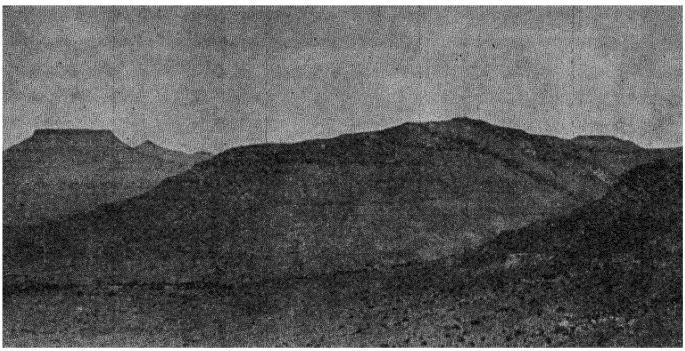


FIG. 44.—Beaufort Beds at Thee Kloof near Beaufort West. Dolerite sill cutting obliquely across strata on the right. Tafelberg and Spitzkop, capped with dolerite, on left. (Rogers.)

Subdivisions.—The multiplicity of vertebrate forms embraced within an evolutionary period covering much of the Permian and Triassic naturally suggested the possibility of a palæontological zoning of this great mass of strata, and as early as 1892 Seeley announced the three-fold division of the Series into the Zones of (1) the Pareiasaurians, (2) the Dicynodonts, and (3) the specialised Theriodonts. Broom carried this a step further by putting forward a subdivision into six zones, which, modified in one particular, has been accepted. Since remains are scarce or absent over wide areas, some aid has had to be sought from lithological characters, which have proved not inconsistent with evidence afforded by the fossils.[1]

[1] For their geographical distribution see F. von Huene, *Die südafrikanische Karroo-Formation als geologisches und faunistisches Lebensbild*, Berlin, 1925 Tafel I; R. Broom, *Bull. Amer. Mus. Nat. Hist.*, 1915, xxv, ii, Fig. 50.

The following Correlation Table of Vertebrate Zones is based on Efremov and Watson.[1]

		South Africa	U.S.S.R.	Europe
Beaufort	Upper	6. Cygnognathus	Capitosaurus	Lower Triassic
		5. Procolophon		
	Middle	4. Lystrosaurus	Benthosuchus	
	Lower	3. Cistecephalus	Scutosaurus Anthodon	Upper Permian
		2. Endothiodon		
		1. Tapinocephalus	" Pelycosaurian "	
Ecca			Titanophoneus	Lower Permian
			Rhopalodon	

Of the three-fold grouping adopted the middle member is relatively thin, but is nevertheless persistent, and has moreover yielded specimens of its zone fossil at a large number of places.

Vegetable remains being extremely scanty and the forms few, the plants cannot be used for zoning, but *Gangamopteris* has not survived from the Ecca, while of the various species of *Glossopteris* characterising the Beaufort the uncommon form *G. retifera* appears to be restricted to the lowest division.

(i) The Lower Beaufort.—In the northern Karroo this group contrasts with the underlying shaly Ecca beds in having bands of fine to medium-grained yellowish feldspathic sandstones alternating with thick bodies of blue, green and occasionally red and purple mudstones and shales, sometimes with calcareous nodules, but towards the north-east such coloured types become scarce. The " mudstones " and " shales " are mostly splintery argillaceous sandstones that crumble on exposure. Ripple-marking is usual.

[1] *Geol. Mag.*, 1942, lxxix, 115.

Conspicuous are the many *local unconformities* and "*wash-outs*" that affect the beds over small distances, sometimes, as seen in cross-section, over only a few yards, the base of a sandstone for example descending into a hollow eroded to a depth of from a few to many feet in the supporting shale, with irregular bedding along the junction, tongueings and lenses of "clay-pellet conglomerate" crowded with flattened lumps of green shale. Fragments of bone may occur, but pebbles of foreign rock are very rare. All this suggests sedimentation upon vast mud- or sand-flats subject to periodical floodings, with the wash-outs marking the temporary channels.

In the southern Karroo the group is like the Ecca beds through the presence of thick bands of spheroidally-weathering greenish or bluish sandstones, greenish flagstones, purplish mud-stones, calcareous concretions, etc. Purple tints are common towards bottom or top; green in the middle of the group. Two persistent "markers" of green cherty rock within the lower portion have been mapped over a wide region in the Great Karroo. This area has yielded the bulk of the reptilian remains, mainly from the tract lying between Prince Albert and Beaufort West and from round about Graaff Reinet, relatively few forms having been found in the northern or eastern regions.

In the thick geosynclinal phase of the south pebble-bearing sand-stones have a wide distribution to the north-east and south-west of East London about the Chalumna River, especially at Kidds Beach, and on the Kwelegha.[1] The pebbles are well rounded to subangular and up to four inches across including not only quartzites, cherts and jaspers, but porphyry, gneiss and red granite, derived apparently from land that lay to the south-east.

Northwards the Lower Beaufort thins progressively to about 1000 feet near Memel, acquiring a "Coal Measure" facies, and indeed including carbonaceous shales and thin coals, best developed near Volksrust and at Somkele in Zululand.

Glossopteris and the silicified wood of *Dadoxylon* have been found here and there, some fresh-water mollusca referable to *Palæomutela* and *Palæanodonta* and a few fish remains, but interest naturally centres in the abundant reptilian genera and species. The massive, heavily-built *Pareiasaurus*, *Propappus*, and *Tapinocephalus*, the sharp-toothed *Titanosuchus*, the lighter, tusked and tuskless *Dicynodon*, and the massive-jawed *Endothiodon* from the south of the Karroo invite attention, the more so since several

[1] E. D. Mountain, *S.A.J.S.*, 1939, xxxvi, 164.

closely allied forms are known from the Permian of northern Russia. Many forms then vanish and are replaced by the therocephalians and gorgonopsians, reptiles with pointed skulls and sharp canine teeth, such as *Scymnosaurus*, *Lycosuchus*, etc. Amphibia are represented by the large *Rhinesuchus*. See Chapter XIII.

(ii) THE MIDDLE BEAUFORT.—The outcrop makes a complete ring within that of the enclosing Lower group, everywhere narrow, save about Middelburg (Cape), and running through Tarkastad, Umtata, Cedarville, Loskop near Bergville, Harrismith, Senekal, Thabanchu, Bethulie and Naauwpoort. It is probably over 1000 feet thick about Rosmead, 800 feet in the Transkei and 500 feet beyond. Conspicuous are its horizons of bright red, maroon and purple mudstones alternating with bluish and greenish varieties and with pale bluish sandstones, capped by a very thick bed of bluish to yellow feldspathic sandstone responsible for bold scarps and plateaux, as at Naauwpoort and along the Drakensberg from Van Reenen's Pass to Botha's Pass.

Skulls or isolated bones are common in the red calcareous concretions, referable largely to the genus *Lystrosaurus*, represented by many species and a host of individuals. Cynodonts and amphibians also occur. A petrified tree 96 feet long, referred to *Dadoxylon sclerosum*, from near Harrismith, is on view in that town.

(iii) THE UPPER BEAUFORT.—This group, also known as the *Burghersdorp Beds*, forms a ring inside that made by the division just described. The maximum development is once again in the south-west, *i.e.* Queenstown, while elsewhere the outcrop becomes progressively narrower owing to thinning of the group, *e.g.* from 2000 feet in the Transkei to 150 feet near Memel in the north; in part this may be due to the progressive overlapping of the Stormberg Series across the Beaufort.

This group is all but indistinguishable from the Middle division excepting that red and maroon mudstones play a more prominent part together with blue and green shales, a blotchy appearance being contributed by patches of green coloration in the red mudstones and *vice versa*; red calcareous concretions are abundant. The widely-spaced sandstones are fine or medium-grained, feldspathic, generally yellow or buff externally, but pale greenish-blue when freshly quarried; thinner dark brown or red varieties

are frequent, also bands of clay-pellet conglomerate with scattered fragments of bone.

The abundant reptiles include the large dicynodont *Kannemeyeria, Erythrosuchus*—remarkable for its bizarre appearance—and various cynodonts such as *Cynognathus* and *Gomphognathus*, which display in their skulls and dentition evolutionary progress in the direction of the mammalia.

The vertebrate remains come mainly from the west, *i.e.* Burghersdorp, Aliwal North, Queenstown and Glen Grey, the lower or Procolophon zone being thin. The amphibians such as *Trematosaurus, Cyclotosaurus*, and *Capitosaurus* are of great interest through happening to be genera characteristic of the Triassic of Central Europe, which points to an incursion of " northern " forms during this period, whereas the reptiles are for the most part " southern " in their aspect.

Both fish and plant remains are scarce and, being generally enclosed in sandstone, are poorly preserved. The fishes come chiefly from near Rouxville. The commonest plant is *Schizoneura* in the form of striated casts, but from the very top of the group a more extensive flora has been obtained, including *Danæopsis, Pterophyllum* and some forms such as *Thinnfeldia, Ginkgoites*, etc., characteristic of the overlying Molteno beds (p. 350).

(d) The Stormberg Series

Historical.—As long ago as 1859 this name was bestowed upon these uppermost strata of the System by Wyley in his manuscript geological map of the Cape. The first detailed geological map of any portion of South Africa was made by E. J. Dunn in 1878 of a part known as the " Stormberg." The term " Molteno Beds " was introduced by A. H. Green.

Subdivisions.—The four-fold grouping is as follows in descending order :—

	Maximum thickness.
4. Drakensberg or Volcanic Beds . .	4500 feet
3. Cave Sandstone	1000 ,,
2. Red Beds	1600 ,,
1. Molteno Beds	2000 ,,

In the Cape, Basutoland, and Natal the succession is a perfectly conformable one up from the Beaufort, but in the north of the Free State, in eastern Zululand and farther to the north the Molteno beds are absent—though reappearing in the Zambezi catchment and also in Hereroland—and the upper divisions of

the Stormberg overlap on to older horizons, though the break may not be patent in the field.[1]

Distribution.—Practically the whole of the area forming the headwaters of the Orange River exceeding 5000 feet in altitude is composed by this formation, including, therefore, the Basutoland mass and the high ground belonging to the Union fringing it. This highly dissected block with much indented margin is about 360 miles long and 200 miles across. Basutoland and the adjoining territory form an intensely broken and most impressive region, much of it exceeding 8000 feet above sea-level and a large part in its north-eastern corner exceeding 10,000 feet.[2]

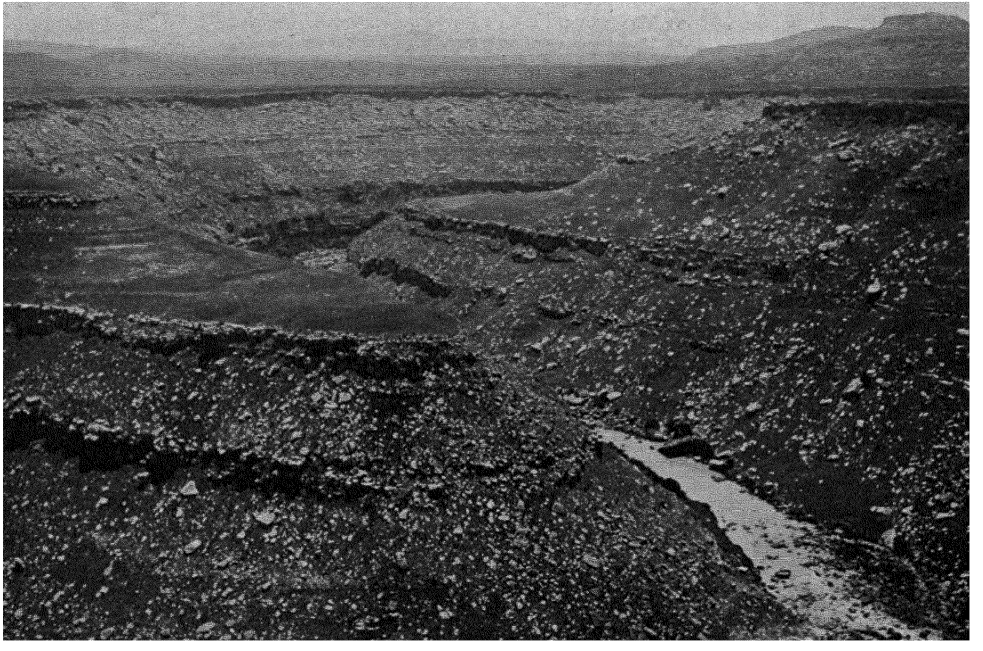
The numerous outlying ridges and peaks still capped with Stormberg beds that border this region testify to the former greater extent of those strata and to the huge amount of erosion that has been effected since the Jurassic, corroboration of which is to be found in the presence, as inclusions in certain of the Kimberlite pipes in the Free State and Griqualand West, of amygdaloidal lavas seemingly of Stormberg age. It has become apparent too that the volcanics underlying the Uitenhage beds of the area to the south of the Zuurberg Range in the Cape must belong to this period, which would indicate a former greater extension to the south as well.

(i) **The Molteno Beds.**—These are readily distinguishable from the deeply-coloured Beaufort beds below and Red Beds above by the typically grey and blue coloration of the shales, the coarse grain and " sparkling " appearance of the dominating sandstones, and the occasional seams of coal. They constitute a " wedge " between groups of coloured strata that tapers from a maximum of 2000 feet between Glen Grey and Elliot to a single thin grit between Harrismith and Memel nearly 300 miles to the north-east, beyond which the Red Beds rest apparently upon the Upper Beaufort. An extension to the south is shown by a downfaulted mass on the Pondoland coast ten miles south-west of Port St Johns, the only spot where any such horizon forms the actual shore.

Striking is the dominantly terraced nature of the country,

[1] A particularly useful discussion of the scattered observations on this Series is contained in the memoir, " The Fauna and Stratigraphy of the Stormberg Series," by S. H. Haughton, *Ann. S.A. Mus.*, 1924, xii, pt. 8 ; see also F. Dixey, *T.G.S.S.A.*, 1936, xxxviii, 73.

[2] G. M. Stockley, " The Geology of Basutoland," *Geol. Mag.*, 1940, lxxvii, 444 ; " Report on the Geology of Basutoland," 1947, Maseru.



The Gorge of the Mooi River, 800 feet deep, cut in Molteno Beds, Maclear, Cape Province. Thick banks of coarse "glittering" sandstones alternate with mudstones and shales.

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due to the resistant character of the main sandstones, which in the south are often from 100 to 200 feet thick, occasionally more, making cliffs running for long distances with the slopes beneath strewn with fallen blocks (Plate XXVIII). The softer strata may consequently be concealed by talus or by the poor sandy soil derived from the disintegration of the thick sandstones.

The " glittering " character of the sandstones is due to the secondary deposition of silica upon certain of the quartz grains in such a manner that crystal faces have been regenerated, with the new quartz in optical continuity with that of the worn particles of sand. The quartz grains, which are white, grey, or even nearly black, attain sometimes a length of half an inch and are invariably accompanied by rather fresh feldspar, mostly orthoclase and microline, in angular or subangular, though occasionally well-rounded, fragments. Such coarse feldspathic grits and sparkling sandstones contain washes of tiny pebbles, are generally markedly false-bedded and weather with a characteristic pitting, while the frequent concretions of pyrite and marcasite form upon oxidation hollow rusty spherical lumps. Conglomerates are not common, but oval and well-worn pebbles of fine-grained quartzites—derived from the Cape System to the south—are not altogether rare in the lower sandstones, though invariably isolated. Scarcely represented in the north, they are more numerous in the south and also larger, attaining a length of from 2 to 8 inches usually, though occasionally exceeding a foot in diameter. Peculiarly, in some of them small cubes of pyrite may have formed at or just within the surface of a pebble. The lowest of these coarse glittering sandstones, named the " Indwe Sandstone " since it crowns the plateau at the Indwe Collieries, is traceable throughout the region occupied by the group, and forms a reliable bench-mark from which the horizons of the different coal outcrops can be defined. The finer varieties of sandstone being friable are not so well exposed ; they are feldspathic, yellowish, grey or cream in colour and furnish a good building stone.

The shales and mudstones are grey or blue, weathering yellow, are often sandy and may include carbonaceous layers and seams of coal ; plant remains are not uncommon. Red coloration and calcareous concretions, so characteristic of the groups above and below, are conspicuously absent. The workable coal-seams are restricted to three horizons ; the lowest is the Indwe Seam

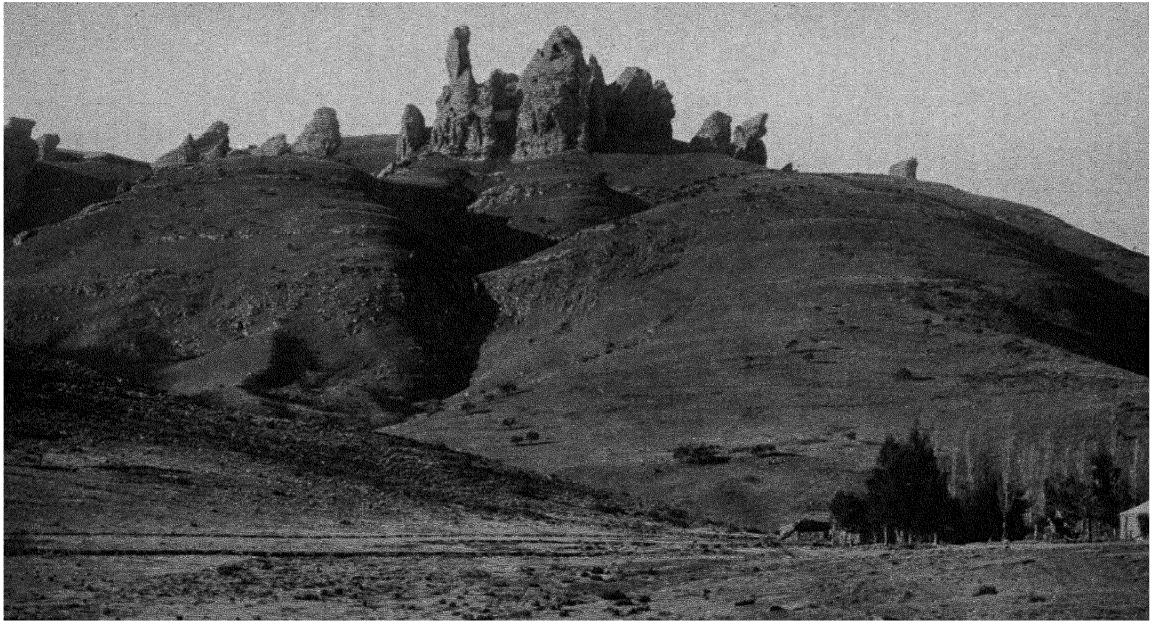
(Indwe, Cala, and Engcobo, though only mined at the first locality), the next is the Guba Seam (Guba Valley near Indwe and Sterkstroom), and the third, from 200 to 300 feet above the first, the Molteno Seam (Molteno, Cyfergat, Bamboes Spruit, Gubenxa in Elliot, etc.). The individual layers of coal seldom exceed a foot in thickness, but may alternate with black shale to produce a thin but workable seam; unfortunately the quality is low, the coals containing streaks of shale and being high in ash. They were deposited in a number of detached areas and at Indwe were affected by contemporaneous erosion. At the head of the Umkomaas River in Natal seams occur of what has incorrectly been termed "oil-shale," actually a variety of bright bituminous coal associated with a material rather like torbanite and with dark shales very rich in plant impressions.

Vertebrate remains are as yet represented only by the cynodont *Cynidiognathus* from Basutoland, but the silicified trunks of *Dadoxylon* are abundant in the sandstones (and occasionally casts in sandstone of stems) and well-preserved plants in the shales, more particularly in those of the lower half of the formation, the most characteristic genera being *Dicroidium* (*Thinnfeldia*), *Tæniopteris*, *Baiera*, *Ginkgoites*, *Callipteridium*, *Schizoneura*, *Stenopteris*, and *Phœnicopsis* (Fig. 53), a flora totally different from that of the preceding series of the Karroo System; a full list will be found on p. 350 and a discussion of its affinities on p. 357.

(ii) *The Red Beds.*—The Molteno Beds pass conformably upwards into this group, which is distinguished by its prevailing coloration, generally occupying the slopes and presenting excellent sections. From a maximum of 1600 feet in Elliot the group thins to under 200 feet in north-western Basutoland and to 300 feet about Harrismith and beyond in the central and northern Transvaal.

Characteristic are the purple and red mudstones and shales—occasionally bleached—together with red sandstones and thick beds of yellow and white feldspathic sandstones, while glittering varieties may be present at the base. Pinkish to bluish calcareous nodules are abundant, some of which have carried barite. Sun-cracked surfaces, worm-tracks and vertebrate footprints have been recorded.

Silicified wood occurs, sometimes as trunks a foot or two in diameter, mostly *Dadoxylon*, but leaves have rarely been pre-



A spur of the Drakensberg north of Elliot rising nearly 2000 feet, showing slopes of Red Beds, with a sheet of intrusive dolerite seen in kloof in centre, crowned by the Cave Sandstone, the pillars of the latter being nearly 300 feet in height.

PLATE XXIX

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served. Important are the vertebrate fossils that have been discovered at various spots in the Cape, Transkei, and Orange Free State, principally dinosaurs such as *Thecodontosaurus*, *Massospondylus*, *Euskelesaurus*, and *Gryponyx*, which indicate a Triassic age. Teeth of the fish *Ceratodus kannemeyeri* Seeley, and the crustacean *Cyzicus* (*Estheria*) complete the list.

(iii) *The Cave Sandstone.*—The junction between the brilliantly coloured and stratified Red Beds and the pale, massive Cave Sandstone is often abrupt, but not infrequently there is a transition due to thick beds of white and yellow sandstone appearing at the top of the former or of deep red and laminated fine sandstones at the bottom of the latter. The Cave Sandstone is an extraordinarily massive, fine-grained rock, frequently hundreds of feet thick, with bedding planes but feebly developed and then mainly towards the base of the band ; a kind of false-bedding is not uncommon, though on a very large scale, so that the individual diagonal planes run continuously through a great thickness of rock.

Fantastic shapes have been evolved under weathering ; indeed no other formation in the country produces such peculiar and picturesque features as the Cave Sandstone where typically developed. Above the village of Elliot it forms buttresses and spikes over 300 feet high (Plate XXIX), while many of the sandstone-topped peaks are very striking. Frequently, where it crowns the ridges, the precipices are undercut at their base or hollowed out locally to form shallow caves, wherefore the name given to this band, while the walls of such rock shelters have often been decorated by the aborigines with remarkably realistic paintings of men and animals done in red, yellow, and black colours upon the pale surface of the rock.

Usually the rock is white or cream-coloured on exposed surfaces, but often it is pink or deep red—particularly at its base—and sometimes a pale blue ; frequently it shows a peculiar mottling. Invariably fine-grained, its central portion in a few localities is practically a mudstone. Lithologically it is in no way different from many of the sandstones of the Red Beds, except in its finer texture, for, generally speaking, the grain of the sandstones becomes finer as one passes from the base to the summit of the Stormberg Series. Considering, however, the enormous area over which it is spread—recollecting the wide region to the north—its uniformity of character is astonishing.

It is made up chiefly of subangular to rounded grains of quartz with subordinate feldspar (mostly microcline) and as accessories tourmaline, garnet, zircon, and white mica. Towards the base irregular pinkish calcareous concretions are common and in the eastern Free State lumps and thin bands of chert.

The Cave Sandstone is fully 1000 feet thick in the upper Orange River valley and near Leribe (Stockley) and 800 feet at the Barkly Pass near Mount Fletcher, and at Thaba Mhlope in Natal; but more usually it ranges from 200 to 300 feet, yet is often much thinner and in a few places is missing, as in the south-west of Elliot. In some places this feature is due to denudation prior to the volcanic outbursts, in others the pouring out of the lavas at an unusually early period prevented the deposition of the fine sand. In Barkly East and Mount Fletcher the sandstone is often split up by intercalations of lava or volcanic ash.

There has been a difference of opinion as to the manner of accumulation of the sandstone; but, as will be argued more fully later on, it is probable that this wonderfully thick, uniform and extensive deposit was essentially *æolian in its origin*, though part of the wind-borne material may have been rearranged through the action of flowing water, mainly at the base, but perhaps at the top as well.

Silicified wood and vertebrate fossils are occasionally found,[1] for example the dinosaur *Thecodontosaurus*, the pseudosuchian *Notochampsa*, and the fish *Semionotus capensis* Smith-Woodward. A thin zone of dark shale in the sandstone at Siberia, Wodehouse district, has yielded the crustaceans *Cyzicus* (*Estheria*) *draperi* Jones and Woodward, and *Lepidurus stormbergensis* Haughton, insect wings, etc.; the first-named has also been obtained from similar bands in the sandstone of Basutoland and of the Platberg, Harrismith.

(iv) *The Drakensberg or Volcanic Beds.*—Normally the Cave Sandstone is followed evenly by the youngest formation of the Karroo System, a succession of lavas which gives rise to dark ranges contrasting strongly with the creamy colour of the precipices below and displaying a regularly stratified and often terraced character owing to the alternations of compact and harder and amygdaloidal and softer varieties.

The volcanic beds form the highest parts of the country in which they occur; seldom indeed does their base drop as low as 5000 feet above sea-level and generally it exceeds 6000 feet. They

[1] S. H. Haughton, *Ann. S.A. Mus.*, 1924, xii, pt. 8.

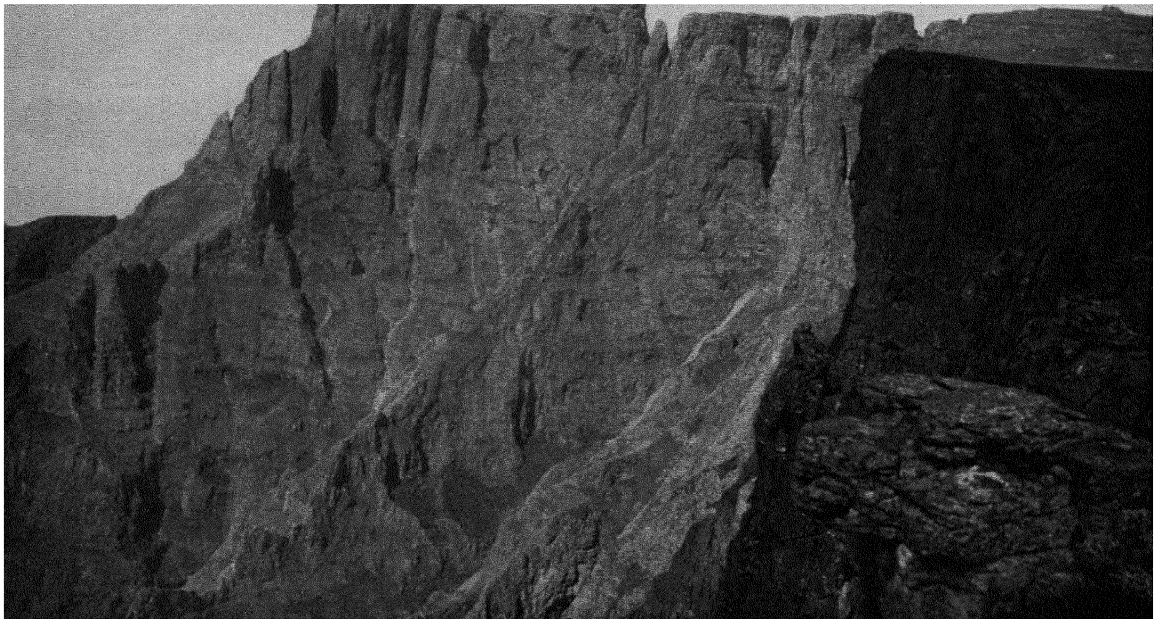

PLATE XXX

Stratification of the Drakensberg Basalts in the Devil's Tooth, Mont-aux-Sources, Natal; altitude of summits over 10,000 feet above sea-level.

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constitute the great deeply dissected mass of Basutoland and the adjoining high ground, the south-eastern side of which is formed by the Drakensberg possessing an escarpment rising from 2000 to 6000 feet above its foot and extending for hundreds of miles. The extensive bare precipices of dark lavas produce scenery of remarkable grandeur, the view in the National Park at the head of the Tugela River being particularly fine. The crests of this highland region, rising to over 10,000 feet, are on the contrary desolate and forbidding. In the Cape and in western Basutoland the group rarely exceeds 3000 feet in thickness; but near Ongeluks Nek in Matatiele quite 4000 feet must be present, and at Mont-aux-Sources a vertical thickness of 4500 feet (Plate XXX).

By far the greater part is formed by lava-streams, but in southern Basutoland, Barkly East, Herschel, Elliot, and Mount Fletcher sandstones, bedded tuffs, and agglomerates are represented towards the base of the formation, showing that sedimentation was renewed at intervals between the outbursts of molten matter. A widespread bed of volcanic ash, hundreds of feet thick, intervenes between the sandstone and the lavas in the southern part of Barkly East and the districts adjoining. Such intercalations are nowhere found more than about 1000 feet above the top of the Cave Sandstone.

A wealth of evidence shows that the relationship to the Cave Sandstone was an intimate one and indicates that, while sand was still "invading" the region, volcanoes were from time to time breaking forth into eruption. At Tent Kop in Maclear lavas and ashes were actually being ejected before the deposition of the Sandstone had commenced, while more to the south local crustal disturbances had been taking place just prior to the onset of volcanicity, involving tilting and faulting, erosion, and local unconformities and the ejection of huge quantities of ash; elsewhere the presence of intercalated lava flows, the inclusion of ashy material or the occurrence of volcanic bombs in the upper part of the Sandstone point to volcanic outbursts during the formation of the latter.

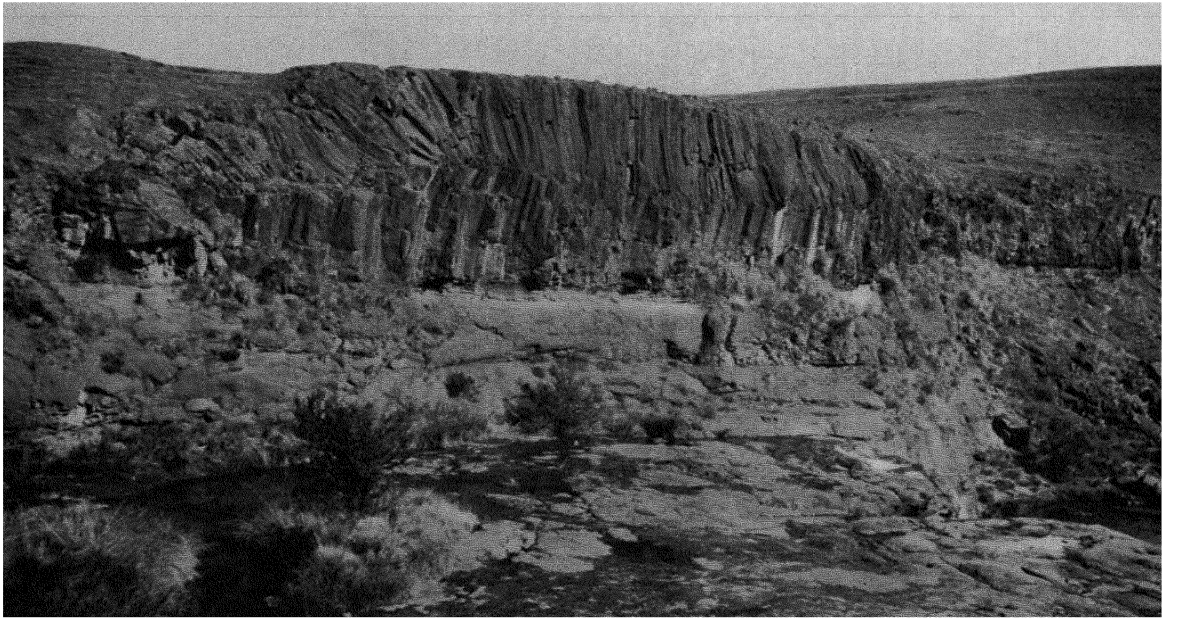
The thick and rudely stratified bed of ash in Barkly East is greenish or purplish in colour and full of fragments of Karroo sediments, inclusions up to several feet across being common; conspicuous are chips of shale from the Red Beds. The volcanic material ranges from the finest comminuted lava to blocks up to a ton or more in weight. Around the great Belmore volcano between Barkly and Rhodes a large area appears to have sub-

sided after the earliest eruptions, the basin so produced being subsequently filled by lavas and tuffs ; a similar tract was found along the Kraai River west of Barkly.

In contrast to the usual regularity with which the lavas rest upon the even top of the Cave Sandstone, several cases can be quoted, one in the Elands Valley below Mont-aux-Sources and another in the Mount Fletcher district, wherein a wide hollow in the sandstone, clearly representing an original channel in the surface of the sand, is occupied by numerous small and irregular flows of lava, parted by lenses of sandstone, etc. As an example the following section (in downward order) from behind the farm Eyrie in Matatiele can be quoted : lavas, 130 feet ; red sandstones and shales, 20 feet ; lavas, 70 feet ; shales, 40 feet; lavas, 630 feet; Cave Sandstone, 100 feet. The red sandstones both here and in Barkly show in the thin section fragments of altered lava and volcanic glass mixed with grains of quartz, microcline, and zircon, probably derived from the same source as the Cave Sandstone. Some of the sandstone bands may well have been deposited under water, but it is not unlikely that many of them were wholly or in great part of sub-aerial accumulation.

Conditions of Eruption.—That much of the volcanic matter in this particular region was poured forth from volcanoes cannot be doubted, but there are reasons for believing that the " central type " of eruption played a rather subordinate part. First, by far the larger number of pipes are filled with brecciated or pulverised sedimentary matter and no lavas ever issued from them. Secondly, with but few exceptions those that must have been active centres pierce the lowest of the basalts only ; no pipe has so far been discovered that has penetrated more than a thousand feet of lava. Thirdly, the necks are restricted to the Basutoland and circum-Basutoland region, 330 miles by 160, and have not yet been detected in association with any of the other extensive regions of lavas to the north and north-west, which apparently are in no way different in their nature from those of this pipe-riddled territory. Fourthly, there is evidence that the pipes are not deep-rooted. It is consequently difficult to avoid concluding that "*fissure eruptions*" must largely—probably entirely in places—have been responsible for the production of the huge volumes of basaltic magma poured out.

Such fissures stand indicated by the narrow dykes of fine-grained dolerite which, as in parts of Basutoland, cut through as much as 3000 feet of lavas though becoming fewer at higher levels. In corroboration is the fact that tuffs, brecciated flows, and agglomerates are represented only at the base of the group, together with some thin intercalations of sandstone and sandy tuff ; higher up comes a monotonous succession of lavas alone. The earlier, fragmental deposits are, so far as can be judged, the outcome of eruptions of the central type.



Columnar basaltic flow resting upon volcanic ash, The Falls, near town of Barkly East.

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The flows in the Basutoland region are evenly superposed and range in thickness up to over 150 feet, the larger ones having spread over areas of one or two hundred square miles. They were poured out, flow after flow, without any lengthy intervals during which the surface of the previous lava sheet could have become weathered. The base of nearly every flow is marked by tubular, branching "pipe-amygdales" produced by the rising through the viscous cooling material of bubbles of gas from the chilled surface of the previous flow. The thinner flows are usually vesicular throughout, but the thick ones have merely a layer of pipe-amygdaloid at the base, passing upwards through feebly vesicular lava into a compact basalt showing hardly any vesicles; higher up, however, steam-holes make their appearance and the top portion of the flow gets quite amygdaloidal. The fact (1) that the stratification of the lavas is everywhere parallel to the sandstone beneath, (2) that nowhere do they make wedge-like bodies, as around modern volcanoes, and (3) that individual flows are traceable for miles, points to the highly mobile nature of the erupted matter.

The basalts of the Transvaal and South-West Africa have not been studied in as much detail as those of the Cape-Natal region, but the observations from Rhodesia are quite in harmony with the above conclusions, and the views set forth above would seem to apply in great degree to these other large yet formerly more extensive lava-fields.

The Volcanic Basin of the Zuurberg.—The basaltic lavas and tuffs first described by Rogers from the southern slopes of the Zuurberg between Sandflats and Enon, parting the Witteberg and Dwyka forming that range from the Uitenhage beds to the south, have a wide distribution and are of post-Dwyka, but pre-Cretaceous age.[1] They show up at intervals along the margin of the Uitenhage "fault-basin" between the Groote River on the west and the Bushmans River on the east, a distance of 100 miles, but are best exposed in the west and again between Mimosa and Enon, the contacts with the older formations unfortunately being nearly everywhere defined by faults.

In the extreme west on the farm Driekuilen about 200 feet of sediments consisting of breccias and conglomerates at the base and

[1] A. W. Rogers, *T.S.A.P.S.*, 1905, xvi, 189; *Ann. Rep. G.C. for* 1905, 12 and 34. S. H. Haughton and A. W. Rogers, *T.R.S.S.A.*, 1924, xi, 235.

followed by red, blue, and white marls, white sandstones and pink tuffs make their appearance beneath some hundreds of feet of the lavas, which are in turn overlain by the basal beds of the Uitenhage Series, with pebbles of tuff from the volcanics in addition to inclusions of Cape rocks. The presence of fragments of bone in the marls suggests correlation with the upper part of the Stormberg Series.

In the belt north of Coerney the volcanics, faulted on the north, dip southwards beneath the Cretaceous, as seen on Slagboom, and in this quarter, and farther to the east as well, pinkish sandy beds and reddish tuffs occur associated with basalts. The lavas are petrologically like those of the Drakensberg, and this fact together with their general relationships makes it almost certain that this group is the representative of the Stormberg Series. See Analysis No. 41.

Special interest attaches consequently to this basin, since it would follow that the " Cape foldings " were largely completed prior to the close of the Stormberg period and that the great overlapping of the uppermost Karroo upon the older strata, already known to occur to the north of Basutoland, extended to the south of the Stormberg as well.

Petrological Characters.—The lavas from the various areas scattered over South Africa are so uniform in their petrological characters that they can conveniently be described together.

While the majority can be described as *basalts* (Analyses Nos. 39-42), a goodly number are more nearly allied to the *augite andesites*, while from a few localities still less basic types, *enstatite andesites*, with brown glassy base have been recorded, *e.g.* Barkly East, Mount Fletcher, and Pronksberg near Jamestown. By the discovery in western Basutoland of olivine-rich types (*oceanites*) Stockley has confirmed the parallelism with the Zoutpansberg and Lebombo volcanics with their well-developed feldspar-free *limburgites* (Analysis No. 43). The *rhyolites* and *dacites* peculiar to the Lebombo and Kaokoveld are dealt with in the relevant sections.

A dark greyish or blackish colour is usual, weathering to a brown, chocolate, reddish or purple hue, while various types are to be found that range from compact rather fresh and crystalline basalts to highly amygdaloidal and generally rather weathered kinds with the gas cavities filled either with agate, chalcedony, quartz, and sometimes calcite, or with zeolites, such as heulandite, stilbite, thomsonite, or scolecite, sometimes mesolite or analcite, Characteristic is the development of pipe-like amygdales from 4 to 10 inches long within an inch or so of the base of a flow uniting upwards, these having been produced [1]

[1] A. L. du Toit, *Geol. Mag.*, 1907, 13.

by the flowing of the viscid lava over a surface of lava, ash, or sandstone through the expansion of steam (from moisture) or gas trapped in the rock beneath; they are more or less perpendicular to the base of the flow, though sometimes considerably inclined thereto. Good exposures frequently show that nearly every flow, no matter its thickness, has its base determined by a layer of "pipe-amygdaloid."

In thin section[1] the feldspar of the earlier generation is most frequently labradorite, that of the second usually andesine, while the augite is commonly colourless; olivine is sometimes present, though seldom in quantity, the majority of samples being free from olivine. Magnetite is always and apatite often present, occasionally enstatite or a green augite; a brown glass containing microlites is found in many of the lavas. The texture ranges from granulitic to sub-ophitic, the type in the latter case being rather like that shown by the smaller sheets and dykes of the Karroo dolerites, but with the ophitic texture rarely so well developed. Varieties with porphyritic feldspars are common in the Zambezi area and Kaokoveld. The specific gravity ranges from 2.8 to 2.95, whereas that of the dolerites runs from 2.95 to 3.0. In the field the more crystalline types often display a rude columnar structure, an unusually good example being shown in Plate XXXI.

The Stormberg Volcanoes.—The number of vents or diatremes filled with lava, agglomerate or tuff is over 170 for the Union and 72 for Basutoland, though more await discovery. In none is the crater-form still preserved, for in every case the necks have been laid bare by denudation. Some are still surrounded by volcanic beds, but the bulk are in contact with the Cave Sandstone or lower horizons. The necks are distributed over a wide and fairly well-defined area, extending from near Steynsburg to Memel and from Modderpoort Junction to Matatiele, a territory 330 miles by 140. The south-eastern limit runs fairly close in under the Drakensberg, yet most suggestively the volcanics must have extended far to the south-east thereof. Outside this region, with the possible exception of certain "pipes" filled with dolerite rock in the Carnarvon district, similar vents have not been recognised.

From the fact that many of the pipes failed to pierce the lavas —or were covered up by younger flows—and that they are now revealed only through erosion, their number and distribution within the area just defined cannot accurately be gauged; but

[1] *Ann. Rep. G.C. for* 1902, 65; *for* 1904, 130; *for* 1911, 112. A photomicrograph of the Deka River (Rhodesia) basalt has been given by F. P. Mennell, *Geol. Mag.*, 1902, 358, and *Introduction to Petrology*, 1910, 132.

they are dotted about in a most irregular manner, occasionally singly, though usually in little groups, while sometimes three or more lie arranged along a line. Such an absence of orderly arrangement is paralleled by the Carboniferous volcanoes of central Scotland, the Permian vents of Fifeshire, those of the Eifel, the Swabian Alps, and the Auvergne.

In regard to size and shape the necks show great variation. The smallest one known was found in Matatiele and is only 4 yards across, but the great majority exceed 100 yards in diameter, while a fair number are fully a mile wide; some are circular in outline, others are much elongated. The great Mod-

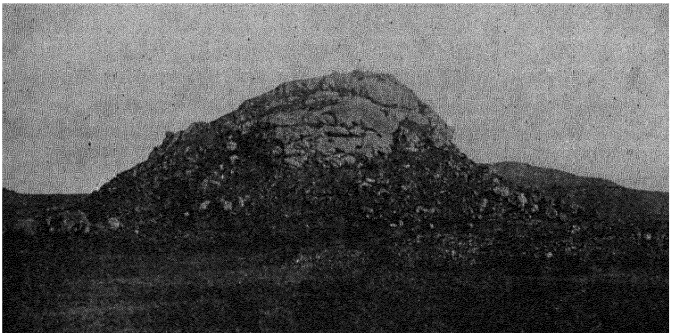
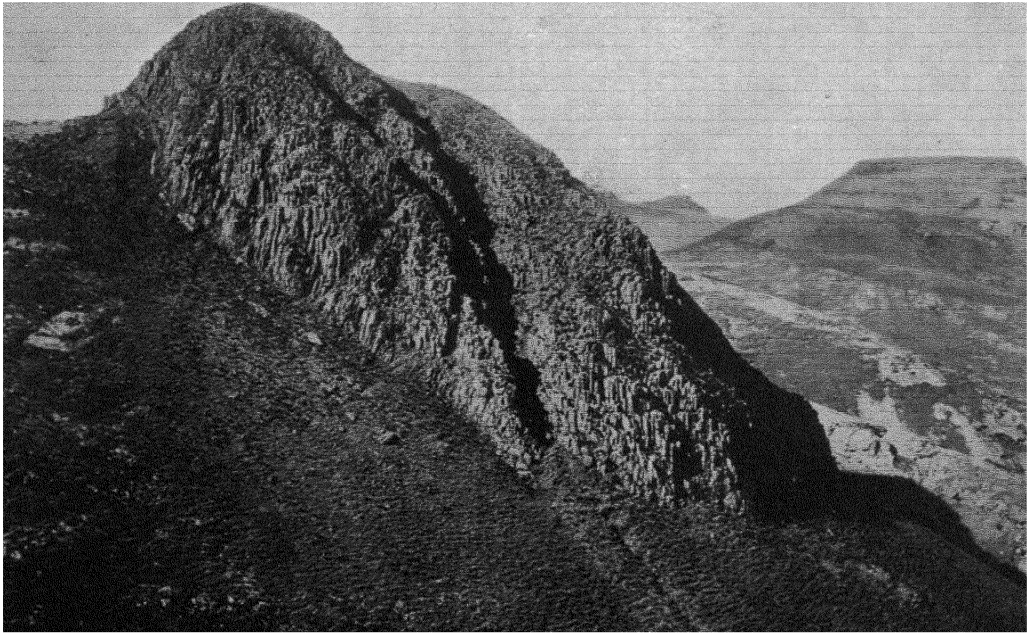


FIG. 45.—Witkop, near Jamestown, an ancient volcanic neck plugged with pale sandstone-like tuff; Stormberg Beds on right and in distance.

derfontein volcano near Jamestown covers an area of fully five square miles, while in the agglomerate filling it occur masses of the encircling strata up to half a mile in length. The area of eruption around Roodepoort and Swartfontein 12 miles to the west is 8 miles long, with the Cave Sandstone highly disturbed along its contacts with agglomerate, tuff, etc. A few necks are plugged entirely with compact lava, for instance that figured on Plate XXXII from the Barkly Pass; many are filled with a light or dark bluish or brownish agglomerate containing fragments of lavas and of sedimentary rocks, the latter usually derived from the Stormberg beds, though pre-Karroo quartzites are occasionally represented. In the larger ones the agglomerate may be pierced by bodies of compact or vesicular basalt, there being in a few



Volcanic plug of columnar doleritic lava piercing the Cave Sandstone, Barkly Pass, north of Elliot. The hill on the right is an outlier of lavas and ash resting on the sandstone.

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cases a connexion still existing between the igneous rock within the vent and the lava-flows that must have issued from the volcano. Generally, however, denudation has proceeded so far that the original connections have long since been destroyed.

In perhaps the majority of cases finely divided sedimentary material so predominates that the stuff filling the neck closely resembles the Cave Sandstone, not only from a distance but even in the hand specimen, the relationship of the rock to the adjacent or enclosing strata and the occasional fragments therein of basalt, sandstone, or shale indicating, however, that it really fills a rudely cylindrical space in the stratified formation, and is not merely an outlier of the Cave Sandstone for which it could be mistaken. Through erosion, the tops of such bodies frequently stand out as conspicuous yellow domes (Fig. 45) or spikes; one of these—the Gat Berg in Elliot—is peculiar in being pierced by a " window " below its summit.

Schwarz has regarded such vent-filling sandstone as having been produced by the shattering in depth of the granitic basement of the Karroo System; but a more feasible explanation is to hand by remembering that the majority of the vents after having been drilled through the crust by the explosive action of gases certainly became extinct without ever having poured out lava. During their brief explosive existence the Cave Sandstone—which was largely æolian in its character—was still in process of deposition, so that fine dust could have mingled with the products of explosion or even have come to fill up the open throat of the volcano. In the case of the neck on Thule near the Cape-Natal boundary the sheet of Cave Sandstone passes obliquely over the edges of the Red Beds and enters the funnel of the vent. No adequate explanation can otherwise be found for these puzzling phenomena, that are seemingly unrepresented among other ancient and modern volcanoes. This hypothesis would account for all the typical minerals of the Sandstone in these siliceous tuffs. Gevers [1] has remarked on the intimate connection of these vents with doleritic bodies situated mostly within the Beaufort beds and has stressed the shallowness of the related volcanism.

It will be instructive to give descriptions of a couple of typical necks. The Belmore Volcano in Barkly East, which must have had a long life, is about three-fourths of a mile across and entirely surrounded by Cave Sandstone that dips in towards its centre. The agglomerate is cut by sills of dolerite and glassy enstatite andesite, while the central plug is formed by a great mass of the latter rock possessing columnar structure; the more acid lavas

[1] T. W. Gevers, *T.G.S.S.A.*, 1928, xxxi, 43.

cut the basic varieties. The lavas forming the surrounding hills are split up by intercalations of sandstone and ash, while a bed of the latter about half a mile to the north of the volcano contains large oval masses of lava, apparently bombs that were ejected during one of the eruptions.

The largest of the Matatiele pipes is on the farm York towards Ongeluks Nek and is about a mile in diameter, filled partly with agglomerate and partly with amygdaloidal and doleritic lava; the latter was the first rock to flow out of the pipe, is still connected with a columnar flow of dolerite that lies upon the Cave Sandstone and is succeeded by amygdaloidal lavas. Brown gritty soil is preserved between some of the lava streams that issued from this vent, while old valleys were carved out of certain of them and filled in by later flows; these point to a long period of activity.

Three complicated areas are to be found in the south of Maclear and near Jamestown respectively, wherein just prior to the main eruptions great disturbances took place involving the sagging and tilting of the strata, their faulting and erosion, the filling of the hollows by thick masses of tuff, and the penetration of the beds by tongues of basalt. In these tracts certain intrusive sheets connected with the network of the Karroo dolerites become vesicular as they rise through the topmost sediments of the Series and merge with undoubted amygdaloidal lavas, indicating that the basaltic flows were locally erupted from fissures as well as from pipes. Schwarz has described a long and broad dolerite-filled fissure, probably of a similar nature, that cuts through the sediments and basalts at Deer Park in Matatiele.

The part played by the volcanic episode in the geological history of the country can be more conveniently dealt with in Chapter XXI, where its relation to previous and subsequent events will be explained.

B. The Lebombo-Buzi Belt

This remarkable strip of country is over 600 miles in length and runs due south-north through the Kruger Game Reserve, joining the Karroo of Zululand with that of the Limpopo, middle Sabi and Buzi valleys. Actually it is the continuation of the eastern limb of the early Jurassic arch, the axis of which stretches through Natal and Swaziland, but which is displaced by numerous oblique faults in the south of Zululand. The structure is that of a monocline with the strata dipping regularly eastwards at

angles of generally from 10 to 20 degrees, though much higher in certain places; the belt is therefore narrow, often not more than 20 miles wide. In the west the sediments rest unconformably upon the ancient rocks and together with the overlying group of basalts make relatively low ground inside the Lebombo, while the succeeding rhyolitic lavas build the range itself, the crest of which constitutes the geographical as well as the political boundary between the Union and Portuguese Territory, rising to from 1500 to 2500 feet above sea-level but broken through by the larger rivers, chief of which are the Usutu, Komati, Olifants, and Limpopo. On the east the rhyolites, followed by more basalts, sink beneath the Cretaceous and Tertiary of the littoral, much of which stands at only a few hundred feet above ocean level.

In the south the full succession of the Karroo, thousands of feet thick—from the Dwyka right up to the basalts—is seen between the Umhlatuzi and Umfolozi rivers, the whole assemblage ending against a powerful oblique fault that brings up the Old Granite on the south-east. From the Letaba River northwards only a thin development of the Bushveld Series is usually present below the volcanics, which include at their base non-feldspathic *limburgites* (Section D).

The Dwyka tillite, displaying all its usual characters, is found to the south and east of Melmoth, at Ulundi on the White Umfolozi, where it rests on a glaciated floor of ancient quartzites. It covers a limited area around the Hlabisa Magistracy, where it reposes on the Table Mountain Sandstone but, just as across in the Transvaal, it grows thinner and more irregular towards the north, being often overlapped by the Ecca shales. Though reported from Kubuta and Hluti Hill in Swaziland, it is not yet known to occur for certain in the Komati Valley or beyond. The Ecca beds persist through Swaziland, passing just west of Komati Poort, Satara and Letaba, thinning northwards and carrying occasional coals of poor quality, as at Nsalitshe Hill, Umbeluzi River and near Komati Poort.[1] The Beaufort beds, much like those of northern Natal, are widely developed in the south and presumably present in the Komati Valley, but must die out to the north. As shown by the fossil plants, the thick, though semi-anthracitic, seams in the St Lucia Coalfield at Somkele belong to this division and probably the upper ones at Tenbosch Siding near Komati Poort.

The Cave Sandstone and Red Beds, together a few hundred feet

[1] J. J. Garrard, "Geology of the Swaziland Coalfield," *T.G.S.S.A.*, 1914, vii, 75.

thick, form a constant horizon beneath the basalts right through Swaziland, across the Komati River—where they were correlated by Kynaston with the Bushveld Sandstone and Marls [1]—and onwards to the Limpopo.

The basalts run evenly inside the Lebombo beyond the Limpopo, and were located by Lightfoot shortly above the coal-bearing division at the junction of the Mkwasini with the Sabi River. Beyond, the sediments are found resting on the Umkondo Series of the Spungabera region, dipping south-eastwards beneath the basalts, which more to the north-east are faulted down against the crystalline rocks of the Statonga area, though traceable according to Mennell almost to Vila Machado and dipping at low angles south-eastwards.

The basalts are of the usual type,[2] blackish, grey, brown, or purplish, ranging from compact to vesicular and with bands of pipe-amygdaloid. A section across the belt through northern Swaziland, which can be taken as typical, shows the (*lower*) basic lavas to be followed by a huge thickness of rhyolites making the crest of the range, overlain by rhyolite-breccias and tuffs and these in turn by the (*upper*) basalts with an intercalation of banded and laminated rhyolitic rocks, which have determined the Little Lebombo west of Lourenço Marques. The thickness of erupted material must be tremendous—several miles at least. The rhyolites are not known to reach the Limpopo, but reappear beyond the Nuanetsi, overlapped thereafter by the presumed Cretaceous " Plateau Sandstone."

Karroo beds, lavas, and acid intrusions are one and all cut by a host of basic dykes with north-south trend set so closely in the Lebombo section as to form a veritable " swarm." They have been regarded as marking the cracks from which issued the successive lava outpourings as the continental margin became stretched and downwarped during the early Jurassic.[3]

The rhyolites—with some dacites—are compact and occasionally coarsely crystalline rocks in various shades of red, green, brown, and mauve, are sometimes studded with spherulites, are generally porphyritic and display flow-structure and banding. In thin section the stony matrix shows phenocrysts of orthoclase, andesine, and quartz, with greenish and often altered augite (see Analysis No. 45). Brown-black pitchstones have also been recorded in which the glassy base exhibits fluidal structure and

[1] H. Kynaston, " The Komatipoort Coalfield," *G.S. Tvl.*, 1906, Mem. 3, and *T.G.S.S.A.*, 1906, ix, 19.

[2] J. M. Henderson, *T.G.S.S.A.*, 1909, xii, 24; R. B. Young, *ibid.*, 1920, xxiii, 98.

[3] A. L. du Toit, *T.R.S.S.A.*, 1929, xviii, 189.

perlitic cracks. Characteristic is the weathering of the rhyolitic rocks with the production of much pisolitic limonite. The tilted basalts are pierced by great elongated masses of pale acid *augite granophyre*—showing affinities with the rhyolites—in Swaziland, on the Transvaal boundary, and in Rhodesia, the last-named body being from 5 to 15 miles wide and running for 100 miles, from south of the Nuanetsi to the Sabi River.[1]

A sandstone intercalation in the rhyolites at Namahacha, west of Lourenço Marques, has yielded poorly preserved remains of *Otozamites*, *Unio*, *Viviparus* (?) and *Palæestheria*, the first-named in agreement with the supposed Liassic age of the volcanics.[2]

C. Central Transvaal—Springbok Flats [3]

North of Pretoria lies the " basin " of the Springbok Flats trending in an east-north-easterly direction for over a hundred miles, a featureless plain with a few detached hills of sandstone just within its margins. The strata are very poorly exposed, only the large number of boreholes enabling the structure and succession to be determined, whence it has been found that post-Karroo warpings of unexpected magnitude have led to the production of a double basin with axes striking east-north-east, while post-Karroo faulting (with north-easterly trend) has helped to determine the north-western side of this great hollow, the base of which descends somewhere about 2000 feet below the rim. The floor, composed mainly of the Rooiberg Felsites or the Red Granite—sometimes of the Waterberg—had originally a considerable degree of unevenness.

Outliers occur around its borders, for example the as yet undefined basin lying just to the north of the Saltpan and those along the Elands Valley to the south-east and also at Pyramid Station not far from Pretoria, occurrences that help to link this area with the main Karroo region to the south. On Palmietfontein, at the base of the Pilansberg, inclusions of shale with *Glossopteris* recovered from a kimberlite pipe piercing the Norite prove a former extension well to the west.

[1] B. Lightfoot, *T.G.S.S.A.*, 1939, xli, 177.

[2] J. V. L. Rennie, *Serv. Ind. Min. e Geol. Col. Moçambique*, 1937, Bol. 1.

[3] See *Ann. Rep. G.S. Tvl. for* 1904, 27; *for* 1905, 29; Geol. Map and Sheet Explanation, Nos. 2, 7, 10.

The succession is as follows, that in the northern Waterberg being given for comparison :—

	Springbok Flats	Northern Waterberg	Cape Province
Amygdaloidal Basalts	1000 feet	400 feet	Volcanic Beds
Bushveld Sandstone	250 to 300 ,,	300 ,,	Cave Sandstone
Bushveld Mudstones	300 ,, 400 ,,	300 ,,	Red Beds
		20 to 70 ,,	Molteno Beds
Upper Ecca Shales	250 to 300 feet	100 to 380 feet	Upper Ecca
Middle Ecca Coal Measures	30 ,, 200 ,,	25 ,, 205 ,,	Middle ,,
Lower Ecca Shales	0 ,, 220 ,,	10 ,, 540 ,,	Lower ,,
Glacial Conglomerate	erratic	erratic	Dwyka Tillite

The wavy line indicates a stratigraphical break.

The glacial conglomerate [1] is known at but few points, such as in the lower part of the Elands Valley on Toits Kraal and in a well on Olievenfontein west of Warmbaths—a pale gritty rock carrying erratics of quartzite and Red Granite; otherwise the Ecca Series rests directly upon the pre-Karroo floor, the Lower Shales existing only in hollows and being overlapped by the Coal Measures. Coals have been struck in the latter during boring operations on a number of farms in the south-east, south, and north, but have been mined only outside the basin proper, at the Rogerston Colliery adjoining Pyramid Station near Pretoria.

The Upper Shales are rather regular throughout the area, being greyish and bluish above and quite black towards their base (a feature of significance when comparison is being made with the Waterberg area) with lenses and bands of brown-weathering fibrous limestone. They give rise to wide areas of red or black clayey soil frequently overlying porous white limestone, as for example along the Saltpan Spruit or near Pienaars River Station, where the material has extensively been quarried for cement manufacture.

The Beaufort beds are *absent*, the Stormberg Series resting upon some division of the Ecca or upon older rocks even, as in the north-eastern margin of the basin or in the township of Warmbaths. The Bushveld " Marls "—which would more appropriately be termed " Mudstones " since the strata are not highly

[1] E. T. Mellor, *T.G.S.S.A.*, 1905, vii, 133; 1905, viii, 33.

calcareous—are, despite their thickness, scarcely ever exposed in natural section, and consist of soft red, purplish, or greenish clays and mudstones, with occasional sandy layers, and are succeeded by the pale yellow or pink Bushveld Sandstone. The latter makes occasional koppies weathered into fantastic shapes, the surfaces frequently pitted and the rock often traversed by parallel joints trending east-north-east, along which induration may have proceeded. The rock is practically identical with the Cave Sandstone, showing under the microscope angular grains of quartz and feldspar, with some rounded ones, zircon, tourmaline, etc. That at Buiskop is gritty and red and makes a good building stone.

The belts underlain by the sandstone are well-timbered, mainly with syringas, and the roads are heavy owing to the pale fine sand, the wash of which, spread over the tracts underlain by the marls, has produced red loamy soils. On the other hand, the country made by the Bushveld amygdaloid can almost always be recognised by the heavy chocolate or black clayey soil, known as "turf" (see p. 486), with occasional outcrops of weathered crumbly rock. The basalts occupy two separate basins, the greatest thickness being 1000 feet in the deep boring on the farm Ludlow.

They are in every way comparable with those of the Drakensberg, but tuffs are absent though some intercalations of sandstone probably occur in the lower part of the group. Limburgite is reported west of Warmbaths by Truter.

Fossils are extremely scarce. *Glossopteris* and *Cardiocarpus* occur in shaly bands in the Coal Measures at Hamanskraal Station. The Stormberg age of the Bushveld Series is indicated by a large dinosaurian femur designated *Gigantoscelus molengraaffi* [1] from the sandstone on Haakdoornbult to the west of Pienaars River Station, while nodules at the base of this group at Slypsteen Drift, Zebedela's Location in the north-east have yielded dinosaurian remains of forms allied to *Euskelesaurus* from the Red Beds.[2]

Unique is an occurrence of coal in the basal part of the Bushveld Mudstones on Vangheining south-west of Warmbaths. The compound seam is 27 feet thick, made up of a number of bands of coal and shale, but, while the ash is considerable, the proportion of volatile matter is phenomenally high—from 35 to 53 per cent.

[1] E. C. N. van Hoepen, *Verh. Geol. Mijn. Gen. Ned. en Kolon.*; Geol. Series, 1916, iii, 107.

[2] W. Anderson, "On the Occurrence of Skeletal Dinosaurian Remains in a Series of Sandstones and Shales at the Slypsteen Drift, 1912."

D. The Zoutpansberg Belt

At the northern end of the Lebombo Belt Karroo beds have been observed by Rogers to enter on the eastern side of the Pafuri Valley and turn westwards along the northern slopes of the Zoutpansberg to the Njelele River at least, either resting on the Waterberg beds or faulted against them and making a shallow syncline with axis trending east-north-east which crosses into Rhodesia, the opposite boundary —on the side nearest Messina—being in part faulted against the granite. The Bushveld Series is dipping northwards below the volcanics, but the Coal Measures are present in places, as in the neigbourhood of the Njelele River below the Hot Springs.

Though perhaps not directly connected therewith, that syncline is continued to the west as a narrow belt, much sand-covered, crossing the Messina road and the railway between Waterpoort and Baobab Stations with expansion to fully 20 miles wide north of the Blaauwberg. It occupies a fault-trough [1] bounded by Waterberg beds on the south and Old Granite on the north, possibly related to that farther west (Section D). Apart from faulting the basal Karroo rests in erosion valleys excavated largely in Waterberg beds and is variable in its nature.

The Glacial Conglomerate is present two miles east of Sulphur Springs and normal conglomerates elsewhere, followed by coal-bearing grits and sandstones that run westwards along the northern foot of the Zoutpansberg and are also faulted down within the latter. The Bushveld Sandstone, silicified in places, produces picturesque ridges just west of the Messina road, as on Castle Koppies, but the lavas to the north and west are greatly concealed by red sand.

Important are the facts observed by Rogers: [2] firstly, that the volcanics along the Messina road and those of the area eastwards to the Pafuri River appear in places to be resting upon a slightly uneven surface of Bushveld Sandstone, and secondly, that they are no longer normal basalts but *limburgites* [3]—a more basic type with little or no feldspar—and are furthermore intimately associated with basic lavas of conspicuously *alkaline character* (nepheline basalts) (Analysis No. 44). Truter has shown that the same holds good north of the Blaauwberg. Since along the lower Letaba such limburgites pass upwards into the normal basaltic sequence, while similar types are known from around Tuli, it

[1] F. C. Truter, *T.G.S.S.A.*, 1946, xlviii, 143.

[2] A. W. Rogers, *T.G.S.S.A.*, 1925, xxviii, 33.

[3] Limburgite was first recorded from this area by F. P. Mennell, see *An Introduction to Petrology*, 1910, 140.

follows that over a wide region the beginning of the Stormberg volcanicity was marked out by ultrabasic and alkaline phases.

E. The North-Western Waterberg

Much farther to the south-west another basin of Karroo commences on the Palala River, known usually as the Waterberg Coalfield,[1] in which on account of the ubiquitous red sand the fortunately abundant borehole evidence has to be relied on very largely to interpret the succession and structure. The basin, which is gently flexed, with axes trending east-north-east, is on its southern side dropped down by a nearly east-west fault against the Waterberg sandstone ; on the north the strata rest on the Old Granite and in the east on the Red Granite, while on the west they pass into the Bechuanaland Protectorate with probably faulted boundaries.

The succession and the relative thicknesses of the several divisions are, as recorded earlier (p. 312), like those of the Springbok Flats, the maximum value of the sediments being about 2000 feet.

At Tafelberg on the Palala River the Coal Measure grits according to Rogers rise from a pedestal of granite, the contact disclosing a glaciated surface with striæ directed S. 30° W., though the glacial tillite is not represented. Westwards on the Limpopo the lowest zone, exposed on Van Jaarsvelts Pan, consists of mudstone with erratics of quartzite, etc., apparently the equivalent of the glacial conglomerate which is known from about Palapye. The Lower Ecca shales are dark and micaceous with sandstones towards their base. The Middle Ecca sandstones, grits, and shales, although thin, carry seams of good coal, *e.g.* on the farm Groot Geluk. Of immense interest, however, is the fact that the lower half of the group of shales identified with the Upper Ecca is highly carbonaceous, and over an area of several hundreds of square miles at least is largely an alternation of dark shales and coals, the latter ranging from streaks to beds many feet in thickness. Indeed, in the Groot Geluk borehole out of 280 feet of such mixed strata, no less than 113 feet or *two-fifths* consisted of bituminous coal, including several workable seams (p. 505). *Glossopteris*, *Vertebraria* and *Cardiocarpus* have been identified.

In addition to its economic importance the field is of concern geologically, since not only are the Middle Ecca seams of the great southern region developed therein, but coals have now made their appearance higher up—in the Upper Ecca—on a horizon that becomes the predominant one in the territory farther to the north, in Rhodesia and Nyasaland.

[1] T. G. Trevor and A. L. du Toit, *S.A.J.I.*, 1922, v, 164 ; W. Wybergh, *Union S.A.G.S.*, 1928, Mem. 19, iii ; *Union S.A.G.S.*, 1945, Bull. 15 ; 1946, Bull. 16.

The dark shales are overlain by 60-300 feet of grey, mauve, chocolate or reddish mudstones provisionally allotted to the Ecca, though resembling the upper portion of the Madumabisa shales of Rhodesia. They are succeeded by 20-70 feet of rather coarse-grained white and purple or brown sandstone containing scattered pebbles recalling the Escarpment Grits, and these by the normal Bushveld Series. Exposed only at Slypsteen Drift on the Limpopo, the purplish mudstones have furnished a few reptilian bones. The Bushveld Sandstone, locally silicified, makes several isolated pinnacles jutting from the bush-clad plain. While yellowish in these knobs, borings show that the material may exhibit repeated alternation from white to red.

F. Bechuanaland [1]

Since the observations of Molyneux, Passarge, and Maufe, numerous traverses have been made within the Kalahari that prove a wide distribution for the Karroo and suggest that beneath the sand these beds may be continuous with those not only of Rhodesia but of Gordonia and South-West Africa. Most of the country is flat and deeply covered by sand with good exposures restricted to the extreme east of the Territory, but useful information has come from boreholes.

The irregular lower boundary is traceable from a point north-west of Molepolole just north of Mochudi to the Waterberg Coalfield, westwards past Palla Road, well to the west of Shoshong, to Palapye Road, thence not far away from the railway to Foley, northwards past the Bushman Mine and thereafter eastwards to the mid-reaches of the Nata River in Rhodesia and beyond.

The Dwyka tillite, resting on an uneven surface of Waterberg beds, crops out three miles south-west of Palapye Station,[2] but has also been struck beneath red sand in two boreholes, one three miles to the south and the other at Mapani Pan farther to the south-east, though absent 25 miles to the north at Toutswe Hill, where the gneiss is directly overlain by Ecca grits. These collectively prove the tillite to be a pale grey rock at least 100 feet thick parted by a band of laminated shales and containing striated and facetted pebbles of various kinds. Laminated beds follow, of the type known from among the Pleistocene glacial deposits as "seasonally banded clays," and are succeeded by from 150 feet to over 200 feet of dark shales that can be correlated with the Lower Ecca. The Middle Ecca sandstones, grits, and shales are over 500 feet thick at Mapani Pan, and have been drilled around Artesia, where they are finer-grained. Good coal has been struck close to Palapye Road

[1] A. J. C. Molyneux, *Q.J.G.S.*, 1903, lix, 266; *P. Rhod. Sci. Assoc.*, 1907, vi, 37; S. Passarge, *Zeit. Ges. Erdk.*, Berlin, 1901, xxxvi, 20; *Die Kalahari*, 1904, chap. xxix.

[2] H. B. Maufe, *T.G.S.S.A.*, 1922, xxv, 68.

and Debeeti Station. *Gangamopteris* has been collected from Toutswe Hill and Artesia and *Glossopteris* from Sisi Siding.

West of Palapye up the basin of the Lotsani River the fine-grained Bushveld Sandstone and Red Marls (called by Passarge respectively the " Ssake Sandstone " and the " Lotsani Shales," and by Molyneux the " Samkoto Series ") form picturesque wooded knolls, the sandstone showing all the characters of its equivalent in the Transvaal, being reddish, fine-grained, false-bedded (Fig. 46) and soft, but locally silicified and so giving rise to peculiar ridges. It passes beneath the basalts that occupy a wide area to the north of Serowe, capped by Kalahari silcrete and sand forming the escarpment of the Loale Plateau,

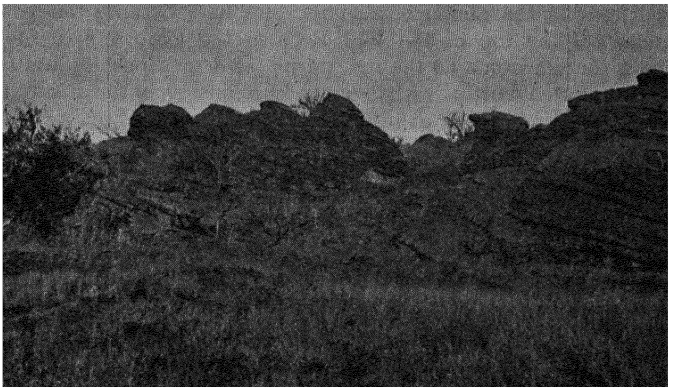


FIG. 46.—Horizontal, cross-bedded Bushveld Sandstone, between Palapye Road and Serowe, Bechuanaland.

and are again exposed along the south-eastern corner of the Makarikari depression according to Macgregor.[1] Similar basalts having been reported by Rogers from the southern side of Lake Ngami and by Rimann from near Aminuis near Gobabis, these lavas not improbably underlie much of the central Kalahari, having indeed been proved by drilling at Kuke and Khari pans far to the north-west of Molepolole.

G. The Tuli-Sabi Trough [2]

Leading from the main Karroo area west of the Bechuanaland railway is a chain of narrow sandstone outliers following the Macloutsie River to its junction with the Limpopo, where begins a shallow syncline

[1] *T.G.S.S.A.*, 1930, xxxiii, 92.

[2] A. J. C. Molyneux, *Q.J.G.S.*, 1903, lix, 266; T. G. Trevor and E. T. Mellor, *G.S. Tvl.*, " Report Reconnaissance North-West Zoutpansberg District," 1908.

trending north of east to the Nuanetsi River—where it unites with the Lebombo zone—the southern edge entering the Transvaal above Rhodes Drift and passing out again above Beitbridge. It is mostly occupied by basalts—together with limburgites—making flattish ground, from below which appears the Bushveld Sandstone showing false-bedding on a very large scale, giving rise to broken country in the neighbourhood of the Limpopo, silicification along joint planes and fracture lines generally trending north-east, or induration along contacts with dolerite dykes coursing west-north-west, having produced prominent ridges and koppies often weathering into pinnacles or with grotesque outlines. Dinosaurian bones referred to *Gryponyx transvaalensis* van Hoepen,[1] were discovered in the sandstone on the farm Wiepe fronting the Limpopo, an important find, because this genus characterises the top of the Red Beds in the Orange Free State. Beneath the sandstone lie the red, purple, and sandy shales and soft sandstones, often mottled with green patches, just as in the area to the south; while underneath at intervals are exposed the Ecca grits and shales both in the Transvaal and Rhodesia, coal seams cropping out in the neighbourhood of the Umsingwane and Singisi rivers, thin and sometimes altered by dolerite. The presence of the Dwyka is suspected.

H. The Middle and Lower Zambezi Region

The Karroo beds must be continuous beneath the alluvium and soil-covered plains of the Buzi and Urema "sunk-lands," for they appear on the western side of the latter at the foot of the upland region to the east of the Gorongoza Mountain and from thence run northward and afterwards west of north in the direction of Tete. Teale reports [2] that in the southern section the belt is only a few miles wide, probably faulted on the west against the gneiss, and consists of reddish, feldspathic, and pebbly and often argillaceous sandstones presumably of Upper Karroo age, since they are followed by basaltic lavas and are also pierced by dykes of basalt (see Fig. 62). Mennell [3] has traced them northwards to the Muira River, the Forest Sandstone being still recognisable. This lengthy strip is only the western edge of a syncline with great development north of the Zambezi between Tete and Port Herald, pitching southwards, its base defined by crystallines in the north, its top by the curving hills of Karroo lavas between the Lupata Gorge and Sena, with the younger Lupata sediments and volcanics occupying the hollow north of Sinjal. The region was intensely faulted during more than one period.

A little to the west of Tete there commences another immense trough

[1] E. C. N. van Hoepen, *Ann. Transv. Mus.*, 1920, vii, 102.
[2] E. O. Teale, *G.J.*, 1915, xlvi, 276; *T.G.S.S.A.*, 1923, xxvi, 115.
[3] F. P. Mennell, *Geol. Mag.*, 1922, 166; *XV Inter. Geol. Congr.*, 1930, ii. 263.

of downwarped or downfaulted Karroo stretching up the Zambezi past Zumbo to join with that of the Wankie-Sengwe area. Two large areas of lavas are traversed by the Ruia River. The Zambezi has taken advantage of this softer belt save where the basement rocks have been exposed at the Kariba Gorge and in the Quebra Baço (Queruabassa) section between Chicoa and Tete with the production of rapids.

The System has been studied in detail along the Nyasaland border,[1] where it is about 18,000 feet thick, and shows the same sequence as in Rhodesia, though each subdivision is much thicker, namely :—(*a*) a Lower division (=Ecca) of current-bedded sandstones and grits succeeded by two groups of shales with coals (and ironstones) parted by sandstones ; (*b*) a Middle one (=Lower Beaufort) of greyish grits and red and purplish marls and sandstones with occasional calcareous concretions and layers, fossil wood and mollusca (*Palæanodonta*) ; and (*c*) an Upper one (=Stormberg) of (i) greyish sandstones and grits with stems of *Rhexoxylon* overlain by a red "desert" sandstone with dinosaur fragments—thus paralleling the Escarpment Grits and Forest Sandstone—and (ii) a group of lavas up to 4500 feet thick to the north of Sinjal, mainly amygdaloidal basalts together with andesites (some carrying enstatite) and agglomerates with an important intercalation near the top of rhyolites with rhyolitic intrusions, that recall the Lebombo succession.

Coals, from a few to many feet in thickness, are widespread, those in the Muatize Coalfield near Tete, now being exploited, being tilted and much faulted and cut by dykes and sills of dioritic composition, such as are common in the Karroo strata of this region. The group has yielded species of *Glossopteris*, *Sphenophyllum*, *Sphenopteris* and *Schizoneura* (p. 348).

I. The North-Western Portion of Rhodesia

Inspection of the geological map will show that an almost complete girdle of Karroo beds surrounds the Rhodesia-Manicaland plateau, interrupted—at the surface at least—by the alluvium and soil of the Buzi Valley on the east and by the Kalahari sand on the west. Furthermore, the System is rather fully developed within the limits of this actual girdle, whereas outside it only the upper divisions are represented. More than half of the circumference of this girdle has already been described ; it remains, therefore, to discuss the remainder situated on the north-west and north.

[1] A. R. Andrew and T. E. G. Bailey, "The Geology of Nyasaland," *Q.J.G.S.*, 1910, lxvi, 189 ; R. Anthoine and J. Dubois, *XIII Inter. Geol., Congr.* 1922, 751 ; F. Dixey, *XV Inter. Geol. Congr.*, 1930, ii, 120, 143 ; F. P. Mennell, *ibid.*, 263 ; C. F. de Andrade, *Esbôço. Geol. Prov. Moçambique*, 1929, chap. vi.

Ignoring for the moment the outliers in the heart of this State, the beds occupy the triangular tract between the Umniati River and Livingstone, much of which really constitutes a kind of lobe from the great " trough " of these rocks that extends down the Zambezi past Feira to Chikoa in one direction and that disappears beneath the sand of the Madenassa veld in the other. For a full hundred miles north-westwards from Bulawayo the formations are exposed mainly along the shallow valleys wherein the mantle of Kalahari deposits has been cut through ; approaching the Zambezi broken country with good outcrops is to be found in which the Escarpment Grits overlook plains of shales or the hard basal sandstones build considerable hills. The strata along the Zambezi display considerable inclination locally, and owe their positions in no small degree to extensive down-warping or to faulting, the main lines of dislocation trending north-eastwards, as can well be seen in the Wankie area (Fig. 47). Thus lowered into the Archæan foundation, the beds were able to secure a considerable measure of protection from active erosion.

Where fully developed, the System must have a thickness of perhaps 3120 feet and can be divided as follows [1] :—

7. Batoka Basalts	+1000 feet		
6. Forest Sandstone	250 ,,	Stormberg Series	
5. Escarpment Grits	550 ,,		
4. Madumabisa Shales	(a) 900 feet	Lower Beaufort	
3. Upper Wankie Sandstones	150 ,,	Upper Ecca	Ecca Series
2. Wankie Shales, Coals and Fireclays	120 ,,		
1. Basal Beds and Lower Wankie Sandstones	150 ,,	Middle and Lower (?)	
(Unconformity)			

[1] The principal literature has been contributed by A. J. C. Molyneux, " The Sedimentary Deposits of Southern Rhodesia," *Q.J.G.S.*, 1903, lix, 266 ; *Ann. Rep. S.A.A.A.S.*, 1908, 1 ; " The Karroo System in Northern Rhodesia," *Q.J.G.S.* 1909, lxv, 408 ; *S.A.J.S.*, 1911, 31 ; " The Geology of Pasipas," *T.G.S.S.A.*, 1919, xxiii, 26.

F. P. Mennell, " The Geology of Southern Rhodesia," *Spec. Rep. Rhod. Mus.*, 1904, ii ; " The Geological Structure of Southern Rhodesia," *Q.J.G.S.*, 1910, lxvi, 353 ; *S.A.J.S.*, 1912, viii, 350.

G. W. Lamplugh, " The Batoka Gorge of the Zambezi," Pap. and Addr., *S.A.A.A.S.*, 1905, ii, 110 ; " The Geology of the Zambezi Basin," *Q.J.G.S.*, 1907, lxiii, 162.

B. Lightfoot, " Geology of North-West Part of the Wankie Coalfield," *S. Rhod. G.S.*, 1914, Bull. 4 ; " Geology of the Central Part of the Wankie Coalfield," *S. Rhod. G.S.*, 1929, Bull. 15.

A. M. Macgregor, " The Karroo Rocks and Later Sediments North-West of Bulawayo," *T.G.S.S.A.*, 1916, xix, 14.

H. B. Maufe, *P.G.S.S.A.*, 1919, xxii, 21.

F. L. Amm, *S. Rhod. G.S.*, 1940, Bull. 35, 75-85.

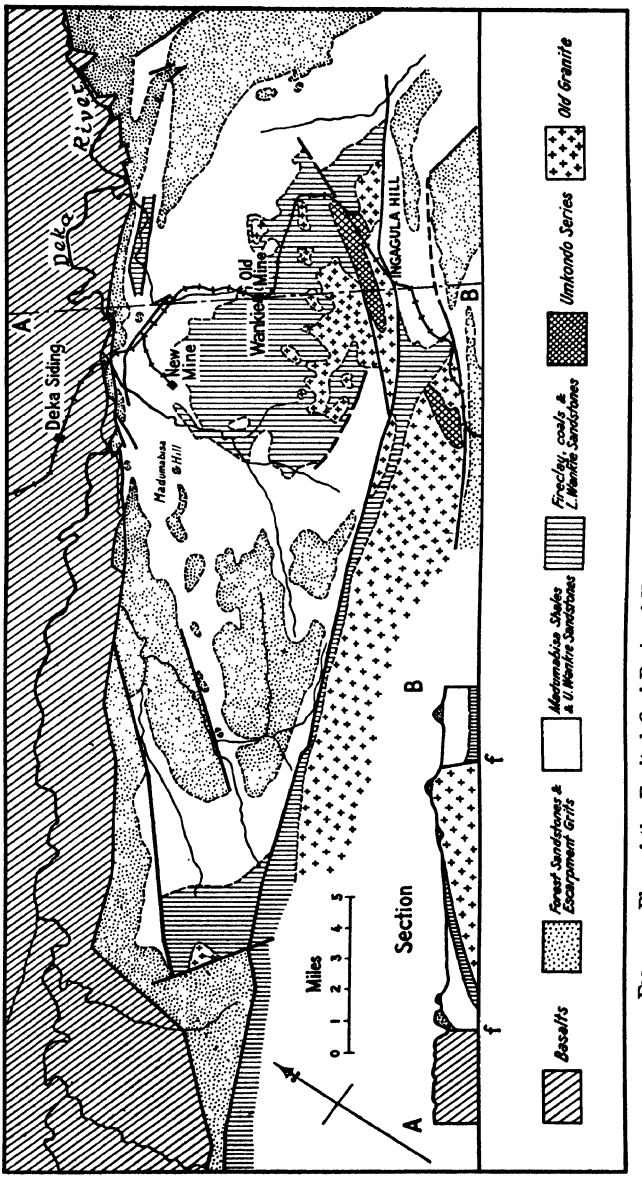


FIG. 47.—Plan of the Faulted Coal-Basin of Wankie (*after* Lightfoot); Black lines—Faults.

On either side of this broad and roughly synclinal belt the Triassic upper divisions overstep the limits of the Permian lower ones and ultimately come to rest upon the pre-Karroo complex, just as in the stretch from Natal to the Transvaal, and it is furthermore not always necessary to proceed far from the axis of this trough to discover such an abbreviated succession; for example, not many miles to the south-west of Wankie the whole of the sediments have vanished and the basalts are apparently lying against a ridge of crystalline rocks (see Fig. 40), and the same is the case on the Linyanti River 40 miles above its junction with the Zambezi. In the Mafungabusi and Shangani areas the Madumabisa Shales thin out eastward and southward causing the Escarpment Grits to overlap on to the Archæan.

On the northern side of the Zambezi "trough" a similar *transgression of the Upper Karroo must take place*[1] for, while between the Luano and Losito Rivers the Grits follow the Madumabisa Shales normally—making a line of red cliffs—in the Kafue Valley 25 miles to the north-west Mennell[2] observed this group and the Forest Sandstone, together reduced to 150 feet, forming a syncline resting on schists and gneisses and overlain by basalts.

Subdivisions.—(1) Strata corresponding with the Dwyka Series and perhaps the Lower Ecca Shales seem to be absent. The oldest beds are the *Lower Wankie Sandstones*, consisting mainly of grits and sandstones, varying in thickness, in part because of irregularity in their floor. About 150 feet is generally attained in the Wankie area. Boulder-beds and conglomerates are finely developed in this basal division within the area immediately to the north of the Zambezi, for instance in the Lufua and Luano Valleys—also in parts of Nyasaland—the rocks with the larger and more angular inclusions being probably in the nature of scree accumulations laid down in a rapidly deepening trough. The only fossils obtained from this division are *Carpolithes* (*Cardiocarpus*) (an Ecca form) from shales at Wankie, and *Glossopteris indica* from the Lufua Valley.

(2) The *Black shale, coal, and fireclay zone*, from 40 to 300 feet thick that follows, called by Molyneux the "Lower Matabola

[1] This problem is discussed more fully by F. Dixey, *T.G.S.S.A.*, 1936, xxxviii, 73.

[2] *Geol. Mag.*, 1922, 166.

Beds," while probably of wide distribution north of the Zambezi, is seemingly restricted to the Wankie area. To it belong the important Wankie seams with interlamination of coal and shale in their upper parts. These coals are regarded by Lightfoot as of " drift " origin. They are succeeded by yellowish-grey hard fireclays up to 80 feet in thickness, from which high-grade firebricks are made, the clays being more siliceous than those of the Transvaal.

(3) The *Upper Wankie Sandstones* (the part equivalent of the Bussé Beds of the Sengwe Valley to the east) are from 75 to 300 feet thick and important through having yielded to Lightfoot an abundant flora which contains according to Walton not only " Southern " forms such as *Glossopteris*, *Cyclodendron*, *Cordaites*, and *Phyllotheca*, but species of *Pecopteris*, *Sphenopteris*, and *Sphenophyllum* that are characteristic of the Lower Permian of the Northern Hemisphere. On palæobotanical grounds this group can be correlated most probably with the Middle Ecca stage.

(4) The persistent *Madumabisa Shales*, termed by Molyneux the " Upper Matabola Beds," are sharply defined from (3) and because of their softness compose the plains stretching eastwards from Wankie to the Mafungabusi. Their thickness ranges from 350 to 900 feet, divisible into two portions :—(*a*) a *Lower Group* of shales, some highly ferruginous (sideritic), black shales and coals, to which horizon belong not only the upper seams at Wankie but all the important coals in the various fields to the east, as on the Lubu, a tributary of the Sebungwe River, on the Busi (Bussé) a branch of the Sengwe River, at Inyoka on the Sessami River, and probably certain to the north of the Zambezi on the Lufua River, around Tete and in the Mount Waller area in Nyasaland. This subdivision can be paralleled with the coal-bearing Upper Ecca of the northern Transvaal.

(*b*) A conformable *Upper Group* of greenish and greyish clays and mudstones with some calcareous nodules and even thin bands of argillaceous limestone (with some gypsum), as well as thin sandstones in the higher horizons. Fossils include silicified wood, fresh-water shells referred to *Palæomutela* and *Palæanodonta*,[1] the ostracod *Darwinula*, the crustacean *Estheria*, teeth and scales of fishes assigned to *Acrolepis molyneuxi*, and fragments

[1] G. Bond, *T.R.S.S.A.*, 1946, xxxi, 125.

of reptilian bones. The discovery by Macgregor [1] in the Sebungwe district of large tapinocephalids near Gunyanka's in the Sengwe Valley along with such fossils provides definite correlation of this group with the lowest reptilian zone of the Beaufort Series of the Cape. This would therefore imply a stratigraphical break at the top of this group, although no angular discordance there has so far been reported.[2]

(5) The *Escarpment Grits* are well named, since this group forms conspicuous bluffs and lines of cliffs, as in those running in a broken line roughly north-eastwards from near Wankie past the head-waters of the Busi and Sessami rivers to the Mafungabusi Mountains, overlooking the plains of Madumabisa shales that extend northwards from their base, repeated in striking fashion in the Luangwa and Lusenfwa valleys north of the Zambezi. Ranging from 40 to over 500 feet in thickness this division is made of strikingly red or brown (occasionally greyish), coarse, current-bedded grits containing banks of subangular pebbles—mainly of quartz, but sometimes of granite or gneiss—while they carry pellets of clay and are in places ferruginous. Intercalated hard, red, and sometimes calcareous clays have also been observed.

Within a wide region north and south of the Zambezi measured sections display considerable variation, but with the tendency towards a finer-grained red centre and coarser and massive bottom and top, the latter being generally redder. The base is disconformable or unconformable.

The stratigraphical parallelism with the Molteno-Red Beds succession, save for the almost universal red coloration, finds support by the discovery of typical species of the *Dicroïdium* (*Thinnfeldia*) Flora, originally at Somabula (p. 351) and subsequently near Siabua in the Sebungwe area, also where the Angwa River crosses the Rhodesian border and in the Kafue and Lusenfwa valleys of Northern Rhodesia. Silicified stems of *Dadoxylon* and *Rhexoxylon* are also frequent.

As displayed in the long tongue along the western side of the Gwelo River that reaches to the railway at Willoughbys—the scene of the noted Somabula Diamond Fields—the strata,[3] often

[1] *Trans. Rhod. Sci. Assoc.*, 1946, xli.

[2] See F. Dixey, *XV Inter. Geol. Congr.*, 1930, ii, 143; F. P. Mennell, *ibid.*, 263.

[3] A. M. Macgregor, *S. Rhod. G.S.*, Bull. 8, 1921, in which previous literature on this remarkably interesting area is cited, the fossil plants being described by A. C. Seward and R. E. Holttum.

referred to as the "Somabula Beds," are 180 feet thick at the most, consisting of red arkoses and pebble-beds (with a thin band of pink or white mudstones at the base) lying on an uneven surface of granite. Fossil tree trunks are plentiful, some in the upright position with their roots still attached. The pebbles are of quartz, quartzite, granite, serpentine, and banded ironstone, but the concentrates from the washing of the disintegrated rocks have yielded an extraordinarily varied collection of minerals, chief of which are chromite, chrysoberyl, corundum (ruby and sapphire), cyanite, diamond, various garnets, gold, staurolite, topaz, tourmaline and gorceixite; the source of some of these has been discovered to lie far to the north. The marvellous variety and contrast in colour displayed by the "wash" make the Somabula concentrates the most remarkable from any of the gem fields in the world. The origin of the diamonds is unknown, but their presence is important as proving sources for this gem *earlier* than the kimberlites. A similar deposit occurs in the Charter district.

(6) The *Forest Sandstone*, white or reddish, massive and fine-grained with the *Basalts* above, is widely distributed, excellently displayed in the flat-topped hills north-west and north of Bulawayo. This band is very like the Bushveld Sandstone of the Transvaal in other respects, such as its peculiar occasional false-bedding, its habit of unequal weathering, the irregular secondary silicification, the presence of calcareous concretions towards the base and the rounding of the sand-grains. This last-mentioned character is developed to perfection and there can be no doubt that the formation was accumulated under *desert conditions*. The red false-bedded sandstone immediately underlying the basalts must indeed be regarded as an ancient dune-sand. Silicified stems of *Rhexoxylon* are not uncommon, while fragments of a small dinosaurian allied to either *Thecodontosaurus* or *Gyposaurus*—both Cave Sandstone genera—and valves of the crustacean *Cyzicus* (*Estheria*) have been obtained.

In the area stretching northwards from Bulawayo down the Bembezi, Umguza and Khami valleys the sinking, slightly uneven Archæan surface is overlain by the Forest Sandstone, from 160 to 200 feet thick, which has a conglomeratic base, next a calcareous sandstone with a pinkish marly portion above, then a thick white to pink feldspathic sandstone, false-bedded, ripple-marked, sun-cracked and in places silicified—the typical material called

" Forest Sandstone "—followed by a thin, coarser dune-bedded red sandstone which is overlain by the lowest basaltic flow.

Within the volcanics thin intercalations of gritty or flaggy sandstones with well-rounded quartz grains are to be found, occasionally silicified and converted into quartzite. The group of alternating basalts and thin sandstones has been called the " Nyamandhlovu Group " from the district of that name north of Bulawayo, recalling the basal part of the Drakensberg Volcanics in Barkly East.

Outliers are known in the eastern portion of Rhodesia, for instance between Salisbury and Enkeldoorn [1] in part still overlain by basalt, while patches occur to the south-east of Umvuma and probably elsewhere for, owing to the ease with which the sandstone breaks down to form pale sandy soils covered with timber, it is not always possible to be sure of the presence of this formation underfoot. Such outliers form links with the Karroo of the Sabi and Limpopo valleys and indicate that formerly much of central Rhodesia, now an axis of crystalline rocks, may have been covered by Upper Karroo beds.[2]

(7) The *Basalts*.—It is likely that the " Batoka Basalts "—so-called by Lamplugh—formerly covered all the north-western part of Rhodesia. Warped, faulted and eroded, their remnants peep out from beneath the Kalahari Sand in two main areas—in addition to isolated patches within the Lower Zambezi Valley, as at the Kafue Bridge :—

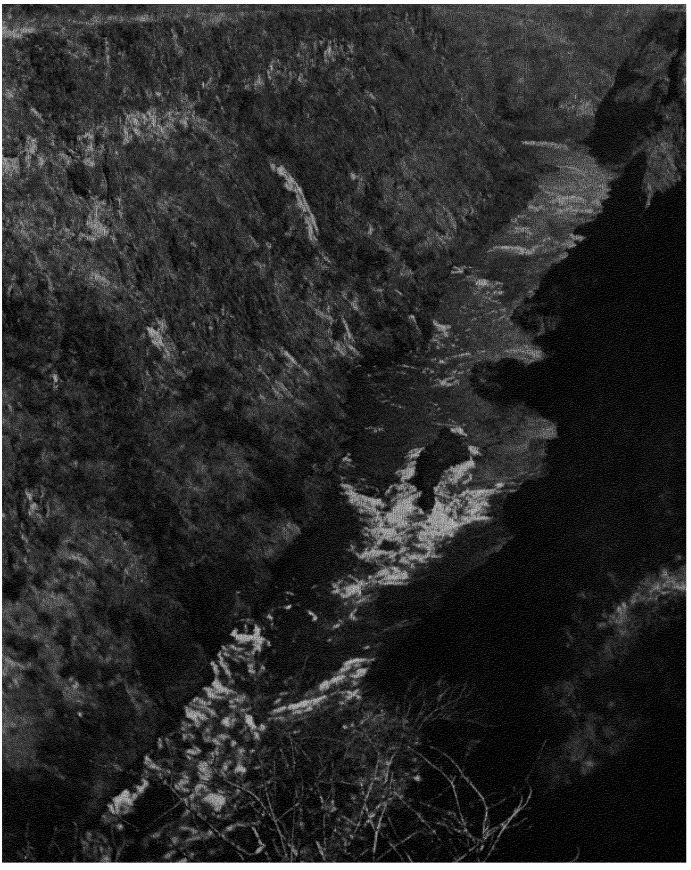
(*a*) The plateau-edge in the east of Mafungabusi-Gokwe and the Shangani River and its westerly extension through the region dissected by the Gwaai and Nata river systems;

(*b*) The triangular tract between Wankie and the Zambezi, the lavas of which stretch along the latter up the Linyanti or Chobe River.

In the first-named area only from two to four separate flows, generally parted by thin bands of sandstone, have been preserved, but beyond Wankie, where they have been dropped down for an unknown depth by the great Deka Fault (Fig. 47), the lavas attain a thickness of well over 1000 feet, and have been cut into a series of picturesque gorges and canyons by the Zambezi and its tributaries, such profiles having been facilitated by the conspicuous vertical jointing in the rock forming the heart of each flow (Plate XXXIII). At the Victoria Falls three flows can be seen

[1] H. B. Maufe, *P. Rhod. Sci. Assoc.*, 1914, xiii, 53.

[2] The stratigraphy of the Forest Sandstone of Rhodesia and the physiographical conditions under which it was formed have been thoroughly discussed by S. H. Haughton, *Ann. S.A. Mus.*, 1924, xii, pt. 8.



The Batoka Gorge looking up from the confluence of the Songwe River, about six miles below the Victoria Falls; depth nearly 500 feet. Stratification of the basalts marked on the left. The "bult" forming the sky-line on the left is made of Kalahari sand.

[*Face page* 326

with intervening flow-breccias—the top of the basal one, bottom of the uppermost one and massive middle one with its jointed centre. The lip of the Falls just opposite the bridge sections a tiny volcanic neck.

The petrology of the lavas has already been dealt with (p. 304); see also Analysis No. 42.

J. Gordonia and Southern South-West Africa [1]

The Dwyka tillite and the overlying shales (the latter with intrusive dolerite) underlie the sandy plain of Gordonia, cropping out at intervals between Upington and Rietfontein. To the west lies a large area extending from Karasburg (Kalkfontein) Station to the Orange River, with downwarping, and just crossing into Namaqualand. Post-Karroo faulting has been responsible for the Great and Little Karas (Kharas) Mountains, and the tillite has been tilted up on the western side of the former; but from near Holoog Station the Karroo beds, resting horizontally on the Fish River Series, extend northwards to well beyond Mariental, terminated on the west by the valley of the Fish River and passing beneath the Kalahari beds on the north-east, in which direction strata ascribed to the Ecca Series appear at intervals. Dolerite is abundant in the Keetmanshoop and Warmbad districts.

While the succession is very like that in the Western Cape there are important differences. The Dwyka glacials are the product of two separate ice-bodies; the Dwyka shales are marine in origin; the lower part of the Ecca—unlike that formation elsewhere—contains much red shale and sandstone; the Beaufort is evidently absent, while amygdaloidal basalts, to be correlated with those of the Stormberg, *transgress across* the several divisions to the north of Mariental.

The Dwyka Series.—The glacials rest on an undulating surface of the older rocks and comprise *two distinct facies*—(1) an older,

[1] The chief literature will be found under:—

P. Range, "Geologie des D. Namalandes," *Beitr. Geol. Erf. D. Sch.*, 1912, pt. 2; "The Topography and Geology of the German S. Kalahari," *T.G.S.S.A.*, 1912, xv, 63; "Ergebnisse von Bohrungen in D.S.W.A.," *Beitr. Geol. Erf. D. Sch.*, 1915, pt. 9.

P. A. Wagner, "The Dwyka Series in S.W.A.," *T.G.S.S.A.*, 1915, xviii, 102; "Geology and Mineral Industry of S.W.A.," *Union S.A.G.S.*, 1916, Mem. 7.

E. Rimann, "Geol. Karte des Khaus-Hottentottenlandes in D.S.W.A.," 1913.

A. L. du Toit, "Karroo System in the S. Kalahari," *T.G.S.S.A.*, 1916, xix, 1.

S. H. Haughton and H. F. Frommurze, "The Geology of The Warmbad District," *Dep. Min. S.W.A.*, 1936, Mem. 2.

thinner, red-weathering type containing (in addition to boulder-beds and fluvio-glacials with well-striated erratics) bedded materials such as buff and pink sandstones and shales, which facies is dominant over the western part of the region—from Mariental to Bushmanland at least—and which, as shown by striated floors, was formed from ice moving southwards from the Windhoek Highlands ; and (2) the normal, thicker, bluish-green tillite followed by boulder-mudstones and shales with erratics, fluvio-glacial conglomerates, calcareous grits, and higher up blue and green shales and flagstones and occasional thin sandstones, which facies prevails in the east and was produced by ice invading the region from the east-north-east, bringing in boulders from Griqualand West and the Transvaal such as Matsap conglomerate, Griquatown jaspers, or Bushveld granite. It overlapped towards the west the previously formed deposits. The whole Series is 500 to 600 feet thick.

At Gibeon the tillite is several hundreds of feet thick, but as a rule its value is much less. Striated and facetted boulders are everywhere abundant, strewing the surface and giving rise to bare stony plains.

Submergence of the area during the melting of the ice led to the deposition of beds of conglomerate and calcareous sandstone, of boulder-mudstones—representing muds into which erratics were dropped by means of floating ice—and of dark shales, evidently laid down in a shallow sea, as the discovery of marine fossils indicates, though how far the ocean followed up the ice-front eastwards is unknown, since mollusca have not yet been obtained to the south-east. These beds are splendidly exposed to the north of Keetmanshoop or in the vicinity of Gibeon, with mile after mile of barren country bestrewn with boulders, pebbles, and lumps of limestone, " gravel Dwyka " or conglomerate.

The dark shaly beds with occasional pebbles have been called by Range the " *Eurydesma beds* " through the occurrence of shells of this rare lamellibranch genus, only known from the " Permo-Carboniferous " of India, New South Wales and Argentina. In addition, calcareous phosphatic concretions in these shales or in the boulder-mudstone—rather like those above the tillite in the south of the Karroo—have yielded species of *Conularia*, *Aphanaia* and *Orthoceras*, and remains of fishes (p. 342).

The dark strata pass upwards into a zone of carbonaceous, white-weathering shales and mudstones with thin streaks of gypsum at outcrops, as seen for instance at Graue Kuppe,

Gariganis, and Kabus to the east, north-east, and north respectively of Keetmanshoop, proved to be the representative of the White Band of the Cape by the discovery at Kabus of a small skeleton of *Mesosaurus*. Some silicified wood coming either from the Dwyka shales or the base of the Ecca has been referred by Gothan to *Dadoxylon scleroticum*.

Ecca Series.—Close to Keetmanshoop and south-west of Warmbad the succeeding strata are, as in the northern Karroo, greyish and bluish shales with some yellow limestones and greenish sandstones, but just within the Kalahari a different facies has been developed. Immediately above the White Band a peculiar bed of calcareous grit can be seen near Kuis on the Molopo in the extreme east, at Wittekrans close to the Cape Border and again at Mariental, in each case succeeded by blue, green, red, and purple shales and flagstones, thin red and brown micaceous and often calcareous sandstones, bands of brown sandy limestones, etc., a type of deposit not represented elsewhere in the Karroo System. The succession along the Molopo from Kuis westwards consists wholly of such alternating bright-coloured sandy and shaly beds, but that in South-West Africa soon passes up into a more arenaceous phase, in which red and yellow colouring is nevertheless common.

Such strata crop out to the south-east of Gibeon and again to the north-east of Mariental within the troughs of the Auob, Elephant River, and Nossob, otherwise our knowledge concerning their nature beneath the covering of Kalahari beds is to be obtained solely from the boreholes, fortunately numerous, drilled in this region. These reveal towards the base, which is sinking in a south-south-easterly direction, a horizon of porous white and brownish sandstones and grits, sandwiched between blue and reddish shales, that is of immense importance as the carrier of the artesian water in this arid region, quite a number of boreholes into it yielding flowing supplies, particularly along the Auob and Elephant rivers (see p. 547). The shales above are followed by red, yellow, and white soft sandstones with some thin bands of red and brown shales, a group that underlies the entire region south-eastward to the Cape border and is of no small thickness, since the deep borehole at Witboois Vley proved 560 feet of such beds, in addition to the 700 feet below that include the artesian stratum. The blue shales struck along the lower Auob just within Gordonia probably indicate the opposite (south-eastern) side of the basin, consequently it is probable that higher horizons of the Karroo will be represented beneath the sands at Arahoab, Gochas, and farther to the east.

To the south-east of Gibeon impressions of *Glossopteris* and *Cordaites hislopi* have been noticed, while silicified wood is common, useful evidence in support of an Ecca age for the strata. Although arenaceous in character, the facies is different from that of the Natal "Coal Measures," which explains why only very thin layers of coal have been struck in the shales above the artesian sandstones.

The Volcanic Group.—The basalts are exposed in a belt extending north-westwards from Mariental, and from that place pass eastwards beneath the Kalahari deposits to reappear between Hofmeyr and Hoachanas, and in small areas about Aminuis beyond the Nossob. Their base, when followed from east to west, transgresses from the Ecca sandstones across the Dwyka, so as to rest upon the Fish River beds to the west of the railway line, thus indicating a break of very considerable magnitude.

The lavas have the same characters as those of the Stormberg Series elsewhere, and may similarly have a few sandstone intercalations in their basal part.

Farther to the north-east on the south side of Lake Ngami such basalts rest directly on pre-Karroo rocks and probably underlie much of the central Kalahari.

Sills of Karroo dolerite characterise the Keetmanshoop district and the area around Karasburg (Kalkfontein) also, intrusive generally in the shales towards the top of the Dwyka Series. Rough-crested ridges have been produced capped with jointed columnar rock and with their sides strewn with blocks of red-weathering dolerite, thus reproducing the scenery in the northern Karroo. Narrow dykes are, however, uncommon.

K. Hereroland and the Kaokoveld.[1]

(*a*) In the Grootfontein and Waterberg districts in Hereroland a number of detached outliers of arenaceous beds cap the higher

[1] G. Gürich, "Deutsch-Südwestafrica," *Mitt. geogr. Ges. z. Hamburg* 1891-92.
J. Kuntz, *Monatsber. D. Geol. Ges.*, 1912, 17.
C. Krause, *Zeits. Prakt. Geol.*, 1913, xxi, 1 (with Map).
E. Reuning, *Geologische Übersichtskarte des mittleren Teils von Südwestafrika*, 1923.
S. Passarge, *Die Kalahari*, 1904, chap. viii, and p. 723.
E. Reuning and F. v. Huene, *Neu. Jahr. f. Min.*, B-Bd. 1925, lii, 94.
F. v. Heune, *Centr. f. Min.*, 1925, Abt. B, 151, 174.
A. Stahl, *Zeits. Deut. Geol. Gesell.*, 1932, lxxxiv, 158.
R. Maack, *Zeits. Ges. Erdk. Berlin*, 1934, 194.
T. W. Gevers, *T.G.S.S.A.*, 1937, xxxix, 317.

ground, such as the Great and Little Waterberg, the Omboroke and Omburo mountains, etc., while in the enormous area of the sandveld to the north-east isolated patches are exposed along the course of the Omuramba Omatako at intervals to the Okavango River. According to Reuning, who has called this formation the *Etjo Sandstone*, the chain which is trending north-eastwards from near Omaruru is faulted down against the older rocks on its north-western side.

The Series, which rests on an irregular surface of crystallines, is made by a variable basal group of grey sandstones, arkoses, and conglomerates followed by red mudstones and shales with coarser bands and those by thick yellow to red fine-grained massive false-bedded sandstones, the whole approaching 2000 feet in thickness. Correlation with the three divisions of the Stormberg is confirmed by the discovery of large saurischian footprints of Triassic types.

(*b*) Horizontal pale sandstones, grits, and arkoses with some red and yellow sandy shales, overlain by amygdaloidal basalts followed by porphyrites and quartz porphyries—which although unfossiliferous belong most probably to the Karroo—have been pierced in the rugged Erongo Mountains [1] north of Usakos by a stock of diorite cut in turn by the light-red " Erongo Granite," and in the bare masses of the Brandberg to the north-west by a circular body of pinkish granite 18 miles in diameter, strongly baking the strata at the contact. The lavas of Messum, to the west, dip regularly in towards a volcanic centre 14 miles in diameter composed of intrusive gabbros, etc., with a granitic core (Martin). A similar granite builds up the conspicuous cone of the Great Spitzkop nearer the coast, while a pinkish granophyre veins fine-grained basic lavas at Cape Cross. The Erongo mass is a coarse biotite alkalic variety with abundant nests of tourmaline. These rather acid bodies (Analysis No. 47), which must have consolidated under a thin cover, are comparable with those of the Lebombo (p. 310).

Across the Ugab River, spreading north-westwards in the coastal region for 250 miles, is Gürich's " Kaokoformation," resting discordantly upon the crystallines and building up chains of high plateaux bordered by table-topped hills and pyramidal peaks, its base descending from 3500 feet just north of the Huab River, and from 2400 feet farther to the north, to below sea-level on the coast. Stahl has reported the country to show block-faulting and narrow graben-structures directed north-west (mostly) and north-east (occasionally). Recent surveys by the Anglo-American Corporation indicate that such rocks, resting on

[1] H. Cloos, *Beitr. geol. Erfor. Deut. Schutz.*, 1913, Heft. 3 ; *ibid.*, 1919, Heft. 17.

gneisses, occupy the coast—mostly lavas with general dips of 10 to 20 degrees inland—so far north as Cape Frio, where sediments intervene.

In several localities such as Doros and Sanitatas a lower group of sediments occurs, namely a scanty basal conglomerate followed by thin pale sandstones, sandy shales with coaly streaks, thin limestones and at the top a stratum of arkose and conglomerate with calcareous concretions (formerly mistaken for volcanic tuffs) which at Doros yielded to Reuning remains of *Mesosaurus*, indicative of a Dwyka age for the sequence. A break must be present above, for the overlying main sandstone which is widely spread in the region is brownish to red, false-bedded and, as shown by a reptilian tooth, *Archæotherium*, of Stormberg age, being succeeded by extensive flows of basalt and augite porphyrite capped by orthoclase porphyry (Analysis No. 46) and rhyolite, of which a thickness of up to 1300 feet has been measured.[1]

Karroo beds are not definitely known from the Kalahari region to the north of Otavi, but a borehole at Andoni on the northern side of the Etosha Pan has pierced a group of sandstones that rather suggests the presence of such strata in that quarter.

[1] E. Reuning, *C.R. XV Inter. Geol. Congr.*, 1929, 28-36.

CHAPTER XIII

THE LIFE AND RELATIONSHIPS OF THE KARROO SYSTEM

Reptilia and Amphibia. Zones. Fauna. Mollusca. Flora. Plant-lists. Correlation.

The Reptilian and Amphibian Life.[1]—The most striking characteristic of the System is the wonderful assemblage that it has furnished of fossil vertebrates, for the most part reptiles, including as well some amphibians and fishes, certain of which belong to genera common to other parts of the world, though most of them, so far as is known, are restricted to South Africa.

Appearing first in the Upper Dwyka shales, remains of REPTILES have been discovered, at intervals, throughout the succeeding divisions of the System right up to the Cave Sandstone, such finds providing material for a vitally illuminating study in vertebrate evolution over a continuous period of fully sixty millions of years and embracing the whole of the Permian and Triassic.

The oldest of the terrestrial reptiles had a continuous bony covering to the skull (Fig. 48, A), pierced only by the two nares for the nostrils, the two orbits for the eyes and a small median opening—the pineal foramen. Such is the case in the Order *Cotylosauria*—" spoon-like lizards "—embracing the Pareiasaurians and Procolophon. In the later forms openings are found in the temporal region, while a reduction in the number of bones in the lower jaw has been brought about. Thus has arisen the Super-Order *Synapsida*—with a single temporal opening on either side, in which are included the Dinocephalians, Dicynodonts, and Theriodonts, the last-named Order containing the Therocephalians, Gorgonopsians, Cynodonts, and Bauriamorphs, far advanced along the line of the mammalia. Lastly comes the Super-Order *Lepidosauria* with two temporal openings on either side of the skull, embracing among others the Thecodonts and Dinosaurs.

[1] Very helpful accounts have been given by R. Broom in Rogers and du Toit, *The Geology of the Cape Colony*, 1909, chap. viii ; by S. H. Haughton, " A Review of the Reptilian Fauna of the Karroo System," *T.G.S.S.A.*, 1919, xxii, 1, and " The Fauna and Stratigraphy of the Stormberg Series," *Ann. S.A. Mus.*, 1924, xii, pt. 8 ; *XV Inter. Geol. Congr.*, 1930, ii, 252 ; by F. von Heune, *Die südafrikanische Karroo-Formation als geologisches und faunisches Lebensbild*, Berlin, 1925; by R. Broom, *The Mammal-like Reptiles of South Africa*, 1932, especially ch. xiii ; by L. D. Boonstra, *S.A.J.S.*, 1932, xxx, 480-94 ; and by D. M. S. Watson, " On Permian and Triassic Tetrapods," *Geol. Mag.*, 1942, 81.

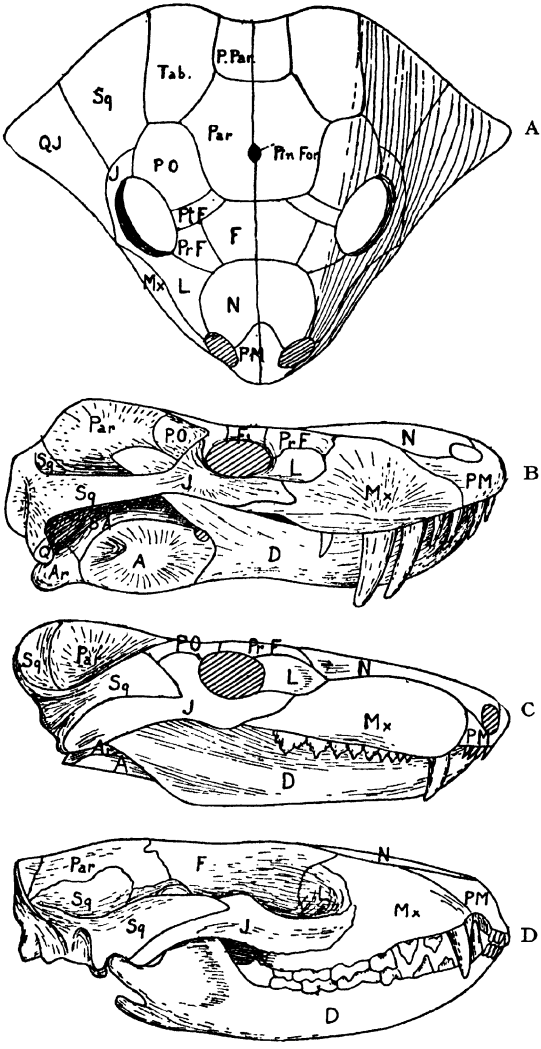


FIG. 48.—Views of Reptilian Skulls. A, *Pareiasaurus*—a Cotylosaur; breadth 18 inches. B, *Lycosuchus*—a Therocephalian; length 9½ inches. C, *Cynognathus*—a Theriodont; length 9 inches. D, *Dasyurus*—a Mammal; length 4 inches. A, *after* Watson; B, C, and D, *after* Broom.

A, Angular; Ar, Articular; D, Dentary; F, Frontal; J, Jugal; L, Lachrymal; Mx, Maxilla; N, Nasal; Par, Parietal; PM, Premaxilla; PO, Postorbital; PrF, Prefrontal; PtF, Postfrontal; PPar, Postparietal; PinFor, Pineal Foramen; Q, Quadrate; QJ, Quadratojugal; SA, Surangular; Sq, Squamosal; Tab, Tabulare.

The earliest reptile met with is *Mesosaurus*, a small aquatic animal about 18 inches in length with narrow pointed jaws furnished with tiny sharp teeth, a very long tail, and slender limbs adapted for swimming (Fig. 49). Its systematic position is not settled, but it is certainly not a primitive kind of Plesiosaur and has been placed in the Proganosauria—" primitive bright lizards "—a division of the Archosauria, by Watson ; by von Huene it is regarded as allied and ancestral to the Liassic Ichthyosaurs. It is confined to the White Band of the

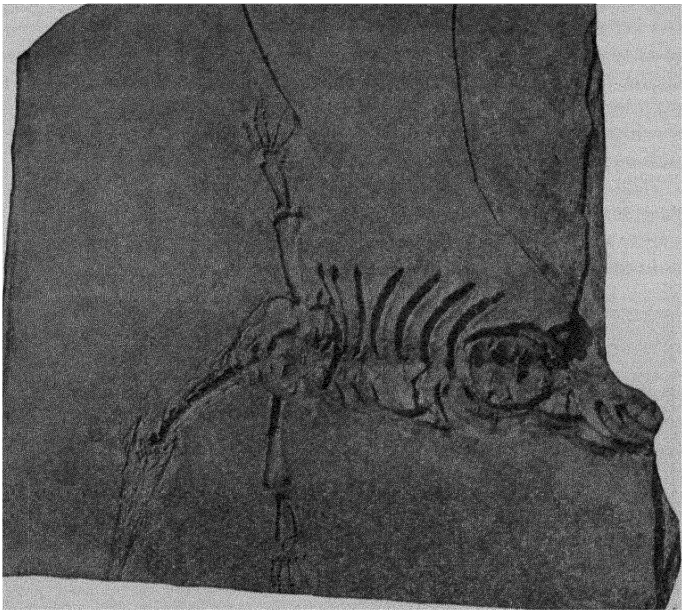


FIG. 49.—*Mesosaurus tenuidens* from the " White Band " of the Dwyka Series.

Dwyka Series in both the Cape and South-West Africa, while an allied form *Noteosaurus* from the Victoria West district comes from the same horizon or from the base of the Ecca.

There is much doubt whether the fragments of the two dinocephalians *Archæosaurus* and *Eccasaurus* from the Prince Albert district came from the top of the Ecca, as supposed. It is from the *Lower Beaufort* that the vast number of forms has been collected, more particularly in the south-western corner of the Great Karroo, between Prince Albert, Beaufort West, and the Nuweveld (Nieuweveld) escarpment ; between Graaff Reinet and Bethesda ; around Fort

found and were covered up rapidly with fine dust or silt. *Procolophon* is a little lizard-like reptile about 18 inches long, having a broad triangular head and, though one of the latest of all the *Cotylosaurs*, yet exhibits many primitive characters.

The *Dicynodonts*—(" double dog-toothed ")—are mainly small animals, many of them not standing more than 3 feet high, though some of the later forms have skulls from 1½ to 2 feet in length, exemplified by the massive *Platycyclops*. The Sub-Order includes *Dicynodon*—of which there is a host of species and varieties—*Cistecephalus*, *Lystrosaurus*, *Pristerodon*, *Emydops*, etc.; while the skeleton is mammal-like, the head is remarkable for having a large horny beak somewhat like that of a tortoise. Some forms, such as *Endothiodon*, with a head extraordinarily large in proportion to the size of its body, are without incisors or canine teeth, but in *Dicynodon* and *Lystrosaurus* the upper jaw possesses a pair of gently curving tusks. It is believed that the genus *Oudenodon*, which is tuskless, is merely the female of *Dicynodon*. *Lystrosaurus*, the zone-fossil of the Middle Beaufort, is like *Dicynodon* in having large tusks, but has large eyes situated near the top of the head and the nostrils also high up, and possesses short limbs, characters which have induced Broom and Watson to regard it as fitted for an aquatic life. Neither Williston nor Haughton agrees with such a conclusion, the latter considering that the characters indicate a digging habit; possibly the animal rooted about in mud for its food. There is a host of individuals known and quite a number of species.

Fairly numerous in the Lower Beaufort beds are the *Therocephalians*—(" wild beast heads ")—animals that ranged in size from a rat to a lion, the majority of forms being known only from skulls, which are more mammal-like than those of the dicynodonts. Among the better known are *Lycosuchus*, *Lycosaurus*, *Scymnosaurus*, *Pristerognathus* and *Ictidosuchoides*. The skulls are narrow with one elongated temporal opening on either side, while the teeth are divided into incisors, one or more enlarged canines, and molars, all simple, pointed, and frequently serrated; there is one occipital condyle, while the roof of the palate is open as in the lizards (Fig. 48, B).

The *Gorgonopsians*—(" terrible eyes ")—most abundant in the upper part of the Lower Beaufort, form an *Infra*-Order of the *Theriodonts* (" wild beast-toothed ") and resemble the *Therocephalians* in their carnivorous dentition, the teeth being divided into incisors, canines, and molars, but differing in the absence of sub-orbital openings in the palate, in the breadth of the temporal region, and in the presence of an incipient secondary palate. The earlier forms include *Scymnognathus*, *Gorgonops*, and *Aelurosaurus*; some of the younger forms such as *Scylacops* and *Cynosuchus* approach the Cynodonts. The form *Clelandina* is peculiar in having no molar teeth.

In the *Cynodonts*—(" dog-toothed ")—the skull is far advanced on the line of evolution of the mammals, having for example a double occipital condyle, a complete secondary palate, a small quadrate, the lower jaw with the dentary greatly enlarged, the molars generally cusped, while the hand and foot are almost mammalian. *Cynognathus*, the zone-fossil of the Upper Beaufort, was a large carnivorous animal about the size of a tiger, but with short limbs; *Gomphognathus* about the size of a large dog. The earliest known, the tiny *Thrinaxodon* (*Ictidopsis*) appearing in the Middle Beaufort, helps to bridge the gap with the Gorgonopsians, while *Bauria* and its allies are small forms of a remarkable type having large sub-orbital openings and forming links with the Therocephalians (Fig. 48, C). The small *Tritylodon* from the Red Beds with tuberculated molar teeth has mostly been regarded as a primitive mammal.

Among the *Archosauria*, having a skull with two temporal openings on either side, is *Erythrosuchus*, a form with an extraordinarily large head (Fig. 51) and short neck, and with teeth more crocodilian in char-

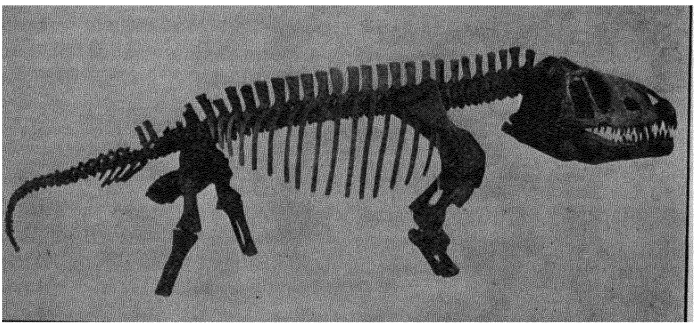


FIG. 51.—Restoration of the skeleton of *Erythrosuchus africanus*; length 15 feet.

acter than mammalian; it is believed by von Huene to have had a mode of life somewhat similar to that of the hippopotamus, although carnivorous. *Chasmatosaurus* is an allied form with regular sharp recurved teeth and a remarkable overhanging snout. *Youngina* is an ancestral form (Eosuchian—" early crocodile ") from which apparently were descended the Pseudosuchians (" false crocodiles "). *Euparkeria* is one of the most interesting forms from the Upper Beaufort, a very small animal with teeth like those of the carnivorous dinosaurs and fore limbs shorter than the hind as in the latter, considered to be ancestral thereto, but also related to the crocodiles and birds.

Sphenosuchus is a Pseudosuchian, ancestral or nearly so to the

crocodiles, with a narrow bird-like skull in which the post-temporal vacuity is very small. It is curious in the absence of clavicles, though the shape of the coracoid is like that in birds ; it has no body armour. *Notochampsa* is a small form with a double row of scutes down the back and with a long-pointed snout ; it was originally regarded as a crocodile, but is now known to belong to the higher pseudosuchia. *Erythrochampsa* is rather similar, but is more crocodilian. These three forms are all from the upper part of the Stormberg Series.

The *Dinosaurs*—(" fearful reptiles ")—are long-necked and long-tailed creatures often of remarkable size, but with the skull astonishingly small in proportion to the rest of the body and with diminutive brain-cavity. The fore limbs are smaller than the hind and the animal seems in many cases to have walked on its hind feet, making use of the tail for support. All the pelvic elements enter the acetabulum ; the orbits are large, while a pineal foramen is absent. The teeth are either deeply socketed or implanted in a groove. The carnivorous forms have sharply pointed teeth, while in the herbivorous types (Predentata) they are compressed and have one or both the margins serrated. Actually the forms comprised under the popular name of " dinosaur " include reptiles from two distinct lines of descent (though both arising from the Pseudosuchia), those more correctly known as the *Saurischia*—(" lizard-like pelvis ")—and the *Ornithischia*—(" bird-like pelvis ")—self-explanatory terms.

Plateosauravus from the Red Beds was a large beast with a femur about 2 feet long, so that it stood perhaps 9 feet high with a total length of some 20 feet. *Euskelesaurus* from the same group is about as massive. *Thecodontosaurus* from the latter and the Cave Sandstone is smaller and more slender, while *Geranosaurus* also from the Cave Sandstone is of particular interest in being the earliest predentate dinosaur known, having teeth with flat, chisel-shaped crowns.

Of the relatively few AMPHIBIANS practically all belong to the Order of the Stegocephalia (" roof-heads ") or Labyrinthodonts. The roof of the flattened skull is formed by a large number of sculptured plates with a pineal foramen situated in the parietal. The lower jaw extends the full length of the skull ; the teeth are numerous, sharply conical with large pulp cavity and walls sometimes highly convoluted by infolding of the dentine, whence the name " labyrinthodont." The body, below as well as above, was mostly covered by bony scales or scutes. The mode of life was of course amphibian.

Of the genus *Rhinesuchus* from the Lower and the Middle Beaufort Beds a particularly fine and almost complete specimen from Senekal has a present length of 7 feet, with shield-shaped head having the orbits fairly well back. *Trematosaurus* from the Upper Beaufort is not quite so large and has a triangular pointed skull with rather small orbits. The heads of *Capitosaurus* and *Cyclotosaurus* from the same group are

both regularly shield-like and very similar; but in the former the auditory notch is open, while in the latter it is closed by the union of the adjacent bones.

The Zones of the Karroo and their Vertebrate Fauna

It was stated earlier (p. 292) that the Beaufort Series is divided into *six palæontological zones*, namely those of (1) *Tapinocephalus*,[1] (2) *Endothiodon*, (3) *Cistecephalus*, (4) *Lystrosaurus*, (5) *Procolophon*, and (6) *Cynognathus*, to which can be added (7) that of the "*Dinosaurs*," which would represent the Red Beds and Cave Sandstone.

As regards the general time-distribution of the chief groups of reptiles, the Dicynodonts are the longest-lived, running right through from the first to the sixth; the Dinocephalians characterise the first, and the Pareiasaurians the first and second at least; the Therocephalians range from the first to the third; the Gorgonopsians existed mainly during the second and third; the Cynodonts occur in the fourth and sixth; the Pseudosuchians during the sixth and seventh, while the *Saurischians* ("Dinosaurs") only make their entry during the seventh.

So extensive is the list that only the better known or established genera can be included in the following summary.[2]

A. Lower Beaufort :—

(1) Reptilia—

Ælurognathus, Aelurosaurus, Akidnognathus, Alopecodon, Alopecognathus, Alopecopsis, Aloposaurus, Anthodon, Arctognathoides, Arctognathus, Arctops. Brachypareia, Bradysaurus, Broomia. Chelyrhynchus, Choerosaurus, Cistecephalus, Clelandina, Cteniosaurus, Cynarioides, Cynosuchus. Delphinognathus, Diaelurodon, Dicynodon, Diictodon, Dinophoneus. Embrithosaurus, Emydochampsa, Emydorhynchus, Emydops, Emydopsis, Endogomphodon, Endothiodon, Eoarctops, Eocyclops, Eosimops, Esoterodon, Euchambersia, Eunotosaurus. Galechirus, Galeops, Galepus, Glanosuchus, Gorgognathus, Gorgonops. Heleosaurus, Heleosuchus, Heliophilus, Hofmeyria. Ictidorhinus, Ictidosaurus, Ictidosuchoides, Ictidosuchus. Jonkeria. Keratocephalus. Leavachia, Lycænodon, Lycænoides, Lycænops, Lycosuchus.

[1] *Tapinocephalus* is here substituted for *Pareiasaurus*, as given in the earlier classifications, since the type *P. serridens* has now been found to characterise a somewhat higher horizon.

[2] This is drawn mainly from S. H. Haughton, "A Bibliographic List of pre-Stormberg Reptilia," *T.R.S.S.A.*, 1924, xii, 51; R. Broom, "The Mammal-like Reptiles of S.A.," 1932, *T.R.S., Edin.*, 1947; J. Brough, "Fossil Fishes from the Karroo System, etc.," *Proc. Zool. Soc. Lond.*, 1931, i, 235.

Megacyclops, Moschops. Nochelesaurus, Notosollasia. Pachyrhinus, Pardosuchus, Pareiasaurus, Pareiasuchus, Platycyclops, Pristerodon, Pristerognathus, Prodicynodon, Propappus. Rachiocephalus. Saurosternon, Scaloposaurus, Scylacognathus, Scylacorhinus, Scylacops, Scylacosaurus, Scymnognathus, Scymnosaurus, Struthiocephalus, Sycosaurus. Tapinocephalus, Theriognathus, Titanosuchus, Trochosaurus, Tropidostoma. Whaitsia. Youngina.

(2) Amphibia—

Laccocephalus, Laccosaurus, Phrynosuchus, Rhinesuchus.

(3) Pisces—

Acrolepis, Atherstonia, Elonichthys.

B. Middle Beaufort :—

(1) Reptilia—

Burnetia, Chasmatosaurus, Dicynodon, Galesaurus, Glochinodontoides, Lystrosaurus, Moschorhinus, Myosaurus, Nythosaurus, Platycraniellus, Prolystrosaurus, Thrinaxodon.

(2) Amphibia—

Lydekkerina, Rhinesuchus (*Uranocentrodon*), *Rhytidosteus ?*

(3) Pisces—

Atherstonia, Caruichthys.

C. Upper Beaufort :—

(1) Reptilia—

Ælurosuchus, Bauria, Cynidiognathus, Cynognathus, Erythosuchus, Euparkeria, Gomphognathus, Howesia, Kannemeyeria, Karoomys, Lycochampsa, Mesosuchus, Microgomphodon, Nythosaurus, Paliguana, Procolophon, Protacmon, Proterosuchus, Sesamodon, Trirachodon, Tritylodon.

(2) Amphibia—

Batrachosuchus, Bothriceps, Capitosaurus, Cyclotosaurus, Kestrosaurus, Micropholis, Microposaurus, Trematosaurus.

(3) Pisces—

Ceratodus, Cleithrolepis, Cœlacanthus, Dædalichthys, Dicelopygæ, Dictyopyge, Helichthys, Hybodus, Hydropessum, Mediichthys, " Oxygnathus."

D. STORMBERG :—

MOLTENO BEDS :

(1) Reptilia—

Cynidiognathus.

RED BEDS :

(1) Reptilia—

Ætonyx, Dromicosaurus, Erythrochampsa, Eucnemesaurus, Euskelesaurus, Gryponyx, Lycorhinus, Massospondylus, Melanorosaurus, Pachygenelus, Plateosaurus, Sphenosuchus, Thecodontosaurus, Trithelodon.

(2) Pisces—

Ceratodus.

CAVE SANDSTONE :

(1) Reptilia—

Aristosaurus, Geranosaurus, Gigantoscelus, Gryponyx, Gyposaurus, Notochampsa, Pedeticosaurus, Thecodontosaurus.

(2) Pisces—

Helichthys ?, Semionotus.

The Affinities of the Karroo Fauna

Great importance attaches to the earliest known reptile *Mesosaurus* from the White Band, since this genus is found elsewhere only in the carbonaceous Iratí shales of southern Brazil. The fishes from the Dwyka shales are, with one exception, well-known Carboniferous or Permian genera.

The Lower Beaufort dinocephalians have been compared by Broom with the curious pelycosaurs possessed of remarkable spiny vertebræ from the Upper Carboniferous and Permian of North America, neither fauna having close alliances with other assemblages ; in South Africa evolution led to the development of a heavy skeleton and massive limbs. Of the few amphibia the Karroo genus *Rhinesuchus* is regarded by Broom as allied to the North American *Eryops*, but the fishes are mainly of European genera.

Since the discovery in Russia by Amalitsky of reptiles surprisingly like those from the Karroo, the researches by Efremov and others have disclosed numerous forms, though their closeness to those of South Africa would seem less than supposed originally. The early Russian faunas, being of Lower Permian age, are more primitive than those of the Upper Permian Tapinocephalus Zone, the alliances becoming

strongest during the later Permian, *i.e.* within the upper part of the Cistecephalus Zone. The large *Inostrancevia* is like *Scymnognathus*, the pareiasaurians *Scutosaurus*, etc., are comparable with *Pareiasuchus* and *Anthodon*, the Dicynodons are typical, while the cynodont *Dvinia* is related to *Cynosuchus* with *Nycteroleter* slightly more primitive than *Procolophon*.[1] Recent accessions from the Cistecephalus Zone have disclosed surprising affinities with the pelycosaurs of North America.

It is not surprising therefore to discover that among forms yielded by part of the Elgin Sandstone of Scotland (supposed to be Triassic, but actually older) *Elginia* is distinctly allied to *Pareiasaurus*, *Geikia* to *Lystrosaurus*, and *Gordonia* very close indeed to *Dicynodon*. It is also held that the Cistecephalus form *Youngina* gave rise to the Upper Beaufort pseudosuchian *Proterosuchus*, from which were probably descended the pseudosuchia of the Elgin Sandstone, *Ornithosuchus*, *Erpetosuchus*, etc., and the German *Aëtosaurus* and *Saltoposuchus*, in addition to the South African forms. *Lystrosaurus* and *Dicynodon* occur in India, Indo-China, and China (Sinkiang), the last along with *Chasmatosaurus*, while an allied form *Sinokannemeyeria* from Shansi and dinosaurians related to those of the Stormberg come from Yunnan.[2]

The cynodonts of the Upper Beaufort are not closely related to any foreign forms, and were apparently the product of evolution in this continent; but the curious *Erythrosuchus* and the large dicynodont *Kannemeyeria* have close allies in *Scaphanonyx* and *Stahleckeria* respectively from the Santa Maria Beds of Brazil.[3] The amphibians on the contrary include a number of typical Lower Triassic European genera in addition to allied forms, while *Batrachosuchus* belongs to a family represented only in India and Australia. The fishes comprise certain genera common in Europe.

After the gap introduced by the Molteno beds a few cynodonts are still to be found, specialised relics from the Beaufort, but the dinosaurs now for the first time appear and become of importance together with the already evolved curious pseudosuchians, a Sub-Order quite well represented as regards number of families. Of the "dinosaurs," *Thecodontosaurus* is a form that ranges in Europe from Middle to Upper Trias and *Plateosaurus* and *Gresslyosaurus* (to which is allied *Euskelesaurus*) from Upper Trias to Rhætic. In South Africa the larger forms appear towards the base of the Red Beds, the smaller higher up; in Europe curiously the reverse seems to be the case. The fish *Semionotus* is characteristic of the Keuper. It is therefore certain that the Cave Sandstone is not younger than Rhætic and is probably of Upper Triassic age.

[1] D. M. S. Watson, *Geol. Mag.*, lxxix, 1942, 112.

[2] C. C. Young, *Amer. Mus. Novitates*, 1946, No. 1324.

[3] A. Smith Woodward, *Geol. Mag.*, 1908, 251. F. von Huene, *Zent. f. Min., etc.*, 1936, B-Bd., B, 507.

The Mollusca and Crustacea

Notocaris from the Upper Dwyka shales of Kimberley is a crustacean allied to *Pygocephalus* of the Upper Carboniferous of the Northern Hemisphere; so is *Anthrapalæmon* from the same horizon at Orange River Station.

Fresh-water lamellibranchs are by no means common. A shell from the torbanite seam of Wakkerstroom can tentatively be referred to *Anthracosia*. The Lower Beaufort has furnished that peculiar association of various species of *Palæomutela* and *Palæanodonta* (including "*Archanodon*") described by Amalitzky from the reptilian deposits of Russia and the Cape and now known from Southern and north-eastern Rhodesia, Nyasaland, and Tanganyika Territory.[1] Another uncommon genus from this division in Natal is the phyllopod *Leaia*, also known from the upper part of the Newcastle stage of New South Wales.

The tiny crustacean *Cyzicus* (*Estheria*) has occasionally been met with, for example, *C. greyi* (Jones) from the Middle Beaufort; *C. draperi* (Jones and Woodward), together with *Lepidurus stormbergensis* Haughton, from a band of shale in the Cave Sandstone, the first named being known from the "Rhætic" of the Argentine, also *Palæestheria lebombensis* and *Unio andradei* from the Volcanic Zone. The ostracod *Darwinula* is recorded from Southern Rhodesia and farther north.

The Flora of the Karroo System and its Affinities

It has been well established that during the latter part of the Carboniferous Epoch a flora came into existence, in the Southern Hemisphere mainly, differing in a number of its elements from that flourishing north of the Equator, one that is called the "*Southern*," the "*Antarcto-carbonic*" or the "*Glossopteris Flora*"[2] from the tongue-shaped frond of its commonest form (Fig. 52). It has been suggested that the elimination of most of the "Northern" and the evolution of the "Southern" types of vegetation may have been affected by the incoming of glacial conditions, for in each of the lands wherein these so-called "Permo-Carboniferous" glacial deposits were laid down, the succeeding beds, if of continental type, have yielded *Glossopteris* and other elements of this peculiar flora, while such European genera as

[1] V. Amalitzsky, *Q.J.G.S.*, 1895, li, 337. W. Hind, *ibid.*, 1903, lix, 287. R. B. Newton, *ibid.*, 1910, lxvi, 242. L. R. Cox, *Q.J.G.S.*, 1932, lxxxviii, 623; 1936, xcii, 32. G. Bond, *T.R.S.S.A.*, 1946, xxxi, 125.

[2] For details concerning its composition and distribution, see E. A. N. Arber, "The Glossopteris Flora," *Brit. Mus. Cat.*, 1905, and for discussion of its origin, A. C. Seward, Pres. Add., *Q.J.G.S.*, 1924, lxxx, p. lxi; *Plant Life through the Ages*, 1931.

Calamites, *Callipteris*, *Alethopteris* and *Odontopteris* are strikingly absent.

Assuming that the principal phase of the great glaciation synchronised in these regions, this flora appears earliest in South Africa,

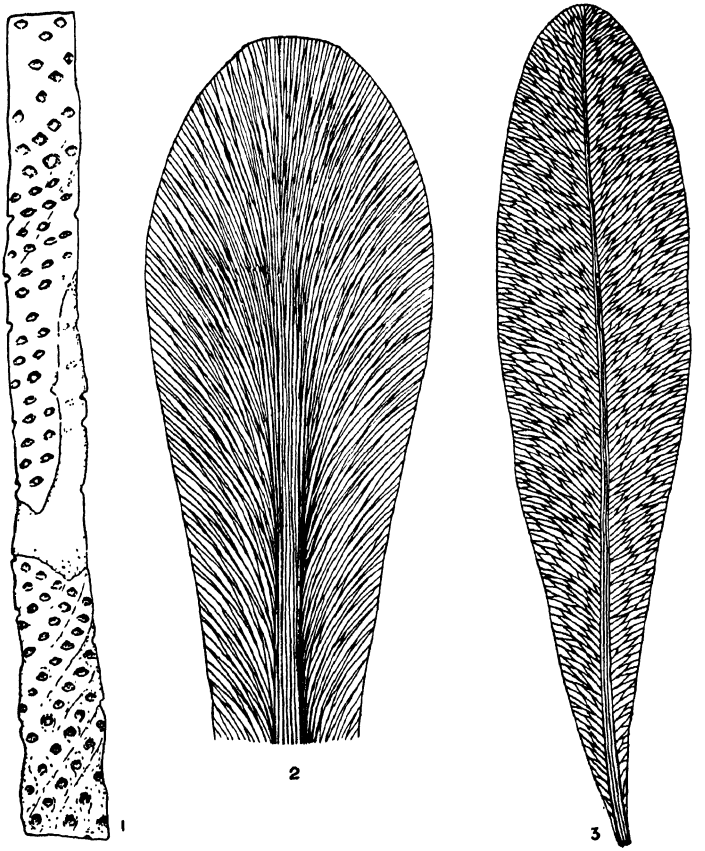


FIG. 52.—Ecca Plants. 1, *Cyclodendron lesliei*; 2, *Gangamopteris cyclopteroides*; 3, *Glossopteris browniana*.

Gangamopteris having been discovered directly beneath the thin Dwyka Tillite in two localities (Vereeniging and near Strydenburg), and it is just possible that this genus originated in this continent. At Bacchus Marsh in Victoria (Australia) this form occurs in sandstones interbedded in the glacials.

In southern Brazil an abundant flora follows the tillite, in which northern elements are well represented by *Lepidodendron, Sigillaria, Bothrodendron,* etc.; but in South Africa that particular stage is apparently reproduced in the Upper Dwyka shales, from which only *Lepidodendron* has been got; in the corresponding strata in India and Australia northern elements are all but absent. The Middle Ecca also includes a number of survivals of the northern forms in the shape of the three genera, just mentioned as occurring in Brazil, though the absence of stems of *Psaronius*, common in Brazil and Europe, is curious. Of peculiar interest is the genus *Ottokaria* from Vereeniging, known only from Brazil and India.

As indicated in the Table given on p. 348, the bulk of the Ecca plants come from Vereeniging and only a few from the Cape, Natal, or Bechuanaland, together with the uncommon assemblage from Wankie with its " Northern " species of *Pecopteris* and *Sphenophyllum*, though *Asterotheca* is now known from Vereeniging. The resemblances of the Ecca flora are with those of the Karharbari and Barakar stages in India, the Greta and Tomago stages in New South Wales, and the Bajo de Velis Beds near Cordoba in the Argentine; from other lines of evidence it can be regarded as of *Lower Permian age.*

The Lower Beaufort—Upper Permian—witnessed a change of flora, the most important alteration being the disappearance of *Gangamopteris*, which has nowhere in South Africa been recorded from beds younger than the Ecca. *Glossopteris* is the prevailing genus—in the various species *browniana, angustifolia, stricta, ampla, damudica, tatei,* etc., while *G. retifera* is highly characteristic and a species almost confined to this division; it can perhaps be regarded as the " zone fossil." *Cordaites* is doubtfully present, but *Sphenopteris* and *Sphenophyllum* have been discovered in Natal. The Equisetales are represented by *Phyllotheca* and *Schizoneura.*

This assemblage, known from the Cape, Free State, Natal, Southern Rhodesia, and Nyasaland, clearly parallels the flora of the Newcastle stage of New South Wales and of the upper half of the Damuda Series of India.

The Middle Beaufort is even more impoverished in forms, *Glossopteris browniana, G. angustifolia,* and fragments of *Schizoneura* being the only ones found, remarkable when one remembers the rather abundant flora of the Upper Permian of Europe. The same is the case in the Panchet stage of India and the Narabeen stage of New South Wales, suggesting that these countries were cut off during the Permian from European floral immigration.

During Upper Beaufort—Lower Triassic—times a few new forms made their entry, such as *Odontopteris* and *Danæopsis*; but it is not until just before the Molteno stage that a sudden increase in the number of genera and species is observed, and the well-known " *Thinn-*

feldia Flora" came into being, so typical of the Upper Triassic and Rhætic in so many parts of the Southern and to a lesser degree of the Northern Hemisphere (Fig. 53). In South Africa the majority of the plants come from the Molteno beds of the Cape-Natal region; a few from the Zambezi trough and Somabula area of Rhodesia. Of impor-

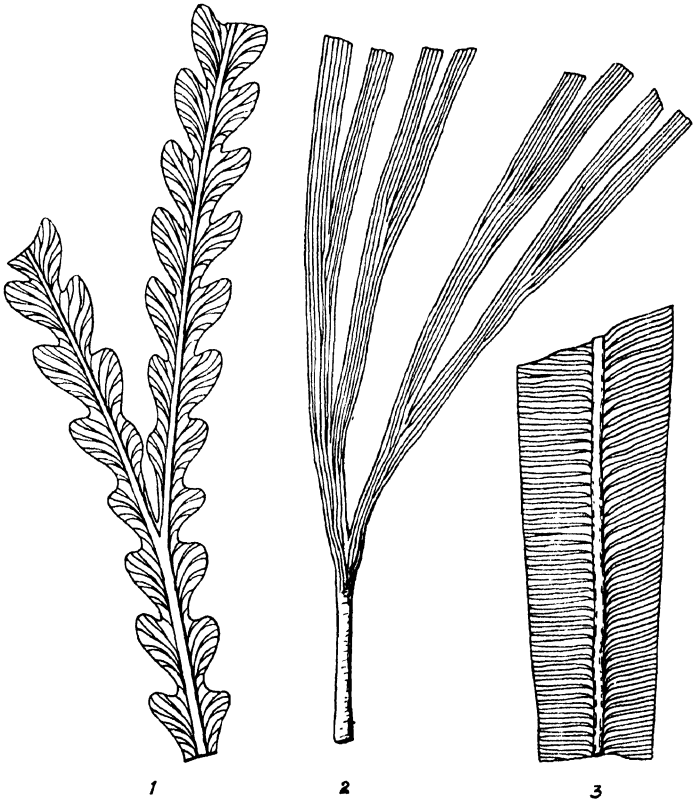


FIG. 53.—Stormberg (Molteno) Plants. 1, *Dicroidium* (*Thinnfeldia*) *odontopteroides*; 2, *Baiera schenki*; 3, *Tæniopteris carruthersi*.

tance now are *Tæniopteris*, the Cycads (*Pterophyllum*, *Pseudoctenis*, and *Zamites*), the Ginkgoales (*Ginkgoites* and *Baiera*), the supposed Pteridosperms (*Dicroïdium* (*Thinnfeldia*), *Callipteridium*, and *Sphenopteris*), the Fern (*Cladophlebis*), and others such as *Stenopteris* and *Chiropteris* of doubtful position. Some of these are well-known genera that had appeared at an earlier date in Europe, but a number of the

typical European Triassic plants have not yet been discovered in this country; on the other hand, *Zamites* and *Pseudoctenis* appear earlier here than elsewhere.

While comparison with Europe shows only a limited community of species, the Triassic floras of the several sections of Gondwanaland display many common species as well as genera. That of the Molteno Beds is surprisingly close in its relationships to the floras of the Ipswich Series of Queensland and Wianamatta stage of New South Wales, of Tasmania, of New Zealand, of the so-called " Rhætic " of Tonkin and the western part of the Argentine, and to a smaller extent of the Parsora and Rajmahal stages of India. That unique fossil wood *Rhexoxylon*, known as yet only from the Stormberg Series of the Union, Rhodesia, southern Nyasaland, and the Beacon Sandstone of South Victoria Land, constitutes a valuable link between South Africa and Antarctica during the Triassic.

After the deposition of the Molteno beds conditions were such that plant life almost ceased to be preserved, but the vertebrate remains in the higher zones denote an age for the Molteno flora not younger than Upper Triassic (Keuper).

The Fossil Plants of the Karroo [1]

A. The Ecca Series

Gangamopteris cyclopteroides, Feist.—Worcester, Vereeniging, Johannesburg, Ermelo, Komati Poort, Umhlali, Bechuanaland (Artesia, Toutswe).

G. kashmirensis, Sew.—Pongola, Greytown?

Glossopteris browniana, Brongn.—Laingsburg, Dundee, Umlalazi, Umhlali, Vereeniging, Middelburg (Tvl.), Sisi (Bechuanaland), Wankie, Tete.

G. indica, Schimp.—Worcester? Pongola, Umlalazi, Umhlali, Vereeniging, Johannesburg, Middelburg (Tvl.), Wankie, Tete, Northern Rhodesia.

[1] The literature is very scattered, but the following are the chief works :—

O. Feistmantel, *Abh. K. Bohm. Ges. Wiss., Prague*, 1889 (vii), iii.

R. Zeiller, *Bull. Geol. Soc., France*, 1896, xxiv, 349.

A. C. Seward, *Q.J.G.S.*, 1897, liii, 315; *Ann. S.A. Mus.*, 1903, iv, pt. 1; *G.S. Rep., Natal*, 1904, ii, 95; *Geol. Mag.*, 1907, 481; *T.G.S.S.A.*, 1907, x, 81; *Q.J.G.S.*, 1908, lxiv, 83.

A. C. Seward and T. N. Leslie, *Q.J.G.S.*, 1908, lxiv, 109.

R. Etheridge, jr., *First Rep. G.S., Natal*, 1902, 67.

R. Kräusel, *Beitr. geol. Erfors. deutsch. Schutz.*, 1928, xx, 17.

A. L. du Toit, *Ann. S.A. Mus.*, 1927, xxii, 289; 1932, xxviii, 369; *XV Inter Geol. Congr.*, 1930, ii, 239.

H. H. Thomas, *Trans. Roy. Soc.*, 1933, Ser. B, ccxxii, 193.

G. brancai, Gothan—Tete. *G. retifera*, Feist.—Vereeniging, Wankie.
G. stricta, Bunb.—Vereeniging. *G. tortuosa*, Zeill.—Wankie.
Vertebraria indica, Royle—Umlalazi, North-west Waterberg.
Cordaites (*Noeggerathiopsis*) *hislopi* (Bunb.)—Newcastle, Umhlali, Pongola, Vereeniging, Johannesburg, Ermelo, Middelburg (Tvl.), Witbank, Wankie, Tete.
Gondwanidium (*Neuropteridium*) *validum* (Feist.)—Vereeniging.
Psygmophyllum kidstoni, Sew.—Vereeniging.
Sphenopteris sp.—Johannesburg, Wankie, Tete.
Sphenophyllum oblongifolium, Germ.; *S. speciosum* (Royle); *S. thonii*, Mahr—Wankie, Tete. *S.* sp.—Ermelo and Natal?
Asterotheca sp.—Vereeniging, Wankie.
Pecopteris arborescens, Schloth.; *P. cf. cyathea*, Schloth.; *P. hemiteliodes*, Brongn.; *P. unita*, Brongn.—Wankie.
Ottokaria leslii, Thomas—Vereeniging.
Phyllotheca zeilleri, Eth. jr.—Umlalazi.
Cyclodendron leslii (Sew.)—Vereeniging, Goamus (South-West Africa), Wankie.
Lepidodendron pedroanum (Carr)—Vereeniging, Witbank.
L. vereenigense, Sew.—Vereeniging.
Sigillaria brardi, Brongn.—Vereeniging.
Stigmaria ficoides, Brongn.—Vereeniging.
Abietopitys perforata, Kräusel—South-West Africa.
Cardiocarpus sp.—Greytown, Pongola, Vereeniging, Hamans Kraal, North-West Waterberg, Wankie.
Dadoxylon arberi, Sew.—Van Wyks Vlei.
D. porosum, Kräusel—South-West Africa.
D. rangei, Kräusel—South-West Africa.
Medullopitys sclerotica, Kräusel—South-West Africa.
Phyllocladopitys capensis, Kräusel—South-West Africa.
Taxopitys africana, Kräusel—South-West Africa.
Conites sp.—Vereeniging.
Samaropsis leslii, Sew.—Vereeniging.

B. The Beaufort Series

1. *Lower Division.*

Glossopteris browniana, Brongn.—Many places in Cape (Graaff Reinet, Fort Beaufort) and in Natal, Somkele.
G. browniana var. *indica*—Graaff Reinet, Estcourt, Somkele.
G. browniana var. *angustifolia*—Graaff Reinet, Somkele.
G. ampla, Dana—Graaff Reinet, Inhluzani (Natal), Somkele, Sisi?.
G. retifera, Feist.—Graaff Reinet, Harrismith, Bergville, Somkele.
G. conspicua, Feist.—Harrismith.

G. cordata, Feist.—Inhluzani (Natal).
G. stricta, Bunb.—Graaff Reinet.
Vertebraria indica, Royle—Somkele.
Sphenopteris alata (Brongn.)—Bergville.
Sphenophyllum speciosum (Royle)—Bergville.
Tæniopteris (*Angiopteridium*) *spathulata* (M'Clelland)—Somkele.
Phyllotheca zeilleri, Eth. jr.—Umlalazi, Somkele, Tanqua Karroo ?.
P. australis, Brongn.—Bergville.
Schizoneura africana, Feist.—Sutherland.
S. gondwanensis, Feist.—Bergville.
Dadoxylon arberi, Sew.—Murraysburg, Philipstown, Umkomaas Valley.
Spiroxylon africanum, Walton—Carnarvon.
Eretmonia natalensis, du Toit—Bergville.

2. *Middle Division.*

Glossopteris browniana, Brongn.—Rosmead, Umkomaas Valley.
G. browniana var. *angustifolia*—Umkomaas Valley.
G. conspicua, Feist.—Harrismith.

3. *Upper Division.*

Dancæopsis hughesi, Feist.—Lady Frere.
Schizoneura sp.—at many localities.

4. *At Top of this Division.*

Dancæopsis hughesi, Feist.
Odontopteris browni, Sew.
Tæniopteris nilssonioides, Zeill.
T. lata, Old.
T. magnifolia (Font.).
Pterophyllum cf. *tietzei*, Schenk.
Nilssonia browni, du Toit.
Strobilites laxus, Sew.
Stigmatodendron dubium, Sew.

(Also those marked in C with *).

C. The Molteno Beds

**Dicroïdium* (*Thinnfeldia*) *odontopteroides* (Morr.).
**D. lancifolia* (Morr.).
**D. feistmanteli*, John.
**D. acuta*, Walk.
D. narrabeenensis, Dun (M. S.).
Tæniopteris carruthersi, Ten.-Woods.
T. spatulata, M'Clell.
Yabiella (*Tæniopteris*) *brackebuschiana* (Kurtz).
**Glossopteris browniana*, Brongn.
G. conspicua, Feist.
Johnstonia coriacea, Walk.
Phœnicopsis elongata (Morr.).
**Neocalamites* (*Schizoneura*) *carrerei* (Zeill.).
Ginkgoites antarctica (Sap.).
G. digitata (Brongn.).
**G. magnifolia* (Font.).
G. moltenensis (Sew.).
Baiera schenki, Feist.

Y. crassinervis (Feist.).
**Callipteridium africanum*, du Toit.
C. stormbergense, Sew.
Cladophlebis nebbensis, Brongn.
C. (*Todites*) *göppertiana* (Schenk).
C. (*Todites*) *rösserti* (*Presl.*).
Chiropteris copiapensis, Solms.
Chiropteris cuneata (Carr).
C. zeilleri, Sew.
Pachypteris acuta, du Toit.
P. incisa, du Toit.
Stenopteris elongata (Carr).
S. densifolia, du Toit.
Lepidopteris natalensis, Thomas.
B. tenuifolia, John.
Pterophyllum inconstans (Braun.).
P. multilineatum, Göpp.
Moltenia dentata, du Toit.
Pseudoctenis capensis, du Toit.
Stormbergia gardneri, Sew.
Pseudoctenis carteriana (Old.).
P. lanciformis, du Toit.
P. spatulata, du Toit.
Rhexoxylon africanum, Bancr.
R. priestlyi (Sew.).
R. tetrapterioides, Walt.
Dadoxylon sclerosum, Walt.
Sphenopteris lobifolia, Morr.

(And fructifications such as *Pteruchus*, Thom., *Umkomasia*, Thom., *Pilophorosperma*, Thom., and *Peltaspermum*, Harris.)

D. The "Somabula Beds" of Rhodesia—Stormberg

Dicroïdium (*Thinnfeldia*) *odontopteroides* (Morr.).
D. lancifolia (Morr.).
D. feistmanteli, John.
Tæniopteris M'Clellandi, Old. and Morr.
Schizoneura gondwanensis, Feist.
Rhexoxylon africanum, Bancr.
Dadoxylon sp.

E. The Lebombo Rhyolite Zone—Stormberg

Otozamites cf. *bechei* (Brongn.).

The Correlation and Age of the Karroo System

The comparison of these various divisions with formations in other lands is beset by difficulties, due chiefly to the fact that the Karroo beds were not laid down in the ocean, neither was such the case with the majority of the equivalent (homotaxial) groups in the remaining parts of the ancient continent known as "Gondwanaland." Marine fossils of past ages have as a rule been more abundant, better preserved, wider spread, and therefore more fitted for instituting such comparisons than the fragmentary remains of plants and land animals that have become entombed in fresh-water and continental sediments. Only now and again could the conditions have been wholly favourable to the good preservation of the latter, whereas in the ocean the hard shells of the

marine organisms would readily have become buried in the sand and mud, retaining generally an unbroken state.

It is, however, fortunate that in each of the countries concerned temporary invasions of the ocean occurred, and the fossiliferous bands resulting therefrom enable the age of the enclosing non-marine strata to be established. With the additional aid of the glacial boulder-beds, generally represented at the base of the comparable systems, of the group of basaltic lavas sometimes present at the summit, and of certain uncommon genera of plants or animals with limited time-distribution, it has become possible to parallel the Karroo System with the equivalent formations in other parts of the world with fair precision, the scheme being indicated in the Table on p. 353. Much depends upon the limit chosen for the top of the Carboniferous (Uralian), the writer setting weight on the boundary advocated by the Russian palæontologists in the type region of the Urals, namely up to and including the zone of *Pseudoschwagerina*, which is somewhat higher than that recognised in many lands.

Across the Atlantic Ocean strata resembling those of the Karroo in an astonishing degree are found in the Falkland Islands and in South America, boulder-beds of glacial origin lying in each case at the base of a mass of sediments containing the Glossopteris Flora.

The descriptions by Andersson,[1] Halle,[2] and, with more detail, by Baker,[3] of the "Lafonian System" of the Falklands show that it covers one-half of the eastern island and exceeds 10,000 feet in thickness, with the massive glacial conglomerate resting upon quartzites that are the equivalent of the Witteberg Series of the Cape. The hard, bluish, or greenish tillite is precisely like the southern Dwyka in its nature and thickness, and is followed by dark cherty shales, by sandstones, and by a thick monotonous group of mudstones and sandstones becoming somewhat more arenaceous towards their top; they closely resemble the facies of the Ecca and Beaufort in the south-western Karroo, a parallelism strengthened by the occasional presence of *Glossopteris*, etc.

In the folded Sierra de la Ventana[4] in eastern Argentina certain formations, the equivalents of the Cape System (p. 262), are followed by a great tillite body exactly like the Dwyka, which

[1] J. G. Andersson, *Wiss. Ergebn. Schwed. Sudpolar-Exped.*, 1901-2, Bd. 3, Lief. 2, Stockholm, 1907.

[2] T. G. Halle, *Bull. Geol. Inst. Upsala*, 1912, xi, 115.

[3] H. A. Baker, "Final Rept. Geol. Invest. in Falkland Islands," 1920-22.

[4] H. Keidel, *An. Minist. Agric., Argentina; Sec. Geologia*, 1916, xi, pt. 3; *Geol. Rundsch.*, 1939, Bd. 30, 148.

	Cape Province	Brazil and Uruguay	Peninsular India	New South Wales	Europe
Stormberg Series	4. Drakensberg Volcanics	Serra Geral Eruptives	Rajmahal Beds		Rhætic to Lias
	3. Cave Sandstone	Botucatú Sandstone	~~~		
	2. Red Beds	Rio do Rasto Beds			Upper / Middle / Lower — Triassic
	1. Molteno Beds	Teresina Stage	Panchet Series: Parsora Stage / Maleri Stage / Panchet Stage	Hawkesbury Series: Wianamatta Stage / Hawkesbury Stage / Narrabeen Stage	
Beaufort Series	3. Upper or Burghersdorp Beds				
	2. Middle				
	1 Lower	~~~ (?)	Damuda Series: Raniganj Stage / Ironstone Shales / Barakar Stage / Karharbari Stage	Newcastle Series / Dempsey Series / Tomago Series / Upper Marine Series	Upper — Permian
Ecca Series	Ecca Beds	Estrada Nova Beds		Greta Stage	Lower — Permian
Dwyka Series	3. Upper Shales: *b.* "White Band" / *a.* Shales	Irati Shales	Talchir Series: Talchir Stage (with glacials at base)	Lower Marine Series (with glacials)	Upper Carboniferous
	2. Boulder Beds (glacial)	Rio Bonito Beds / Itararé Series (largely glacial)			
	1. Lower Shales (in South) | ~~~ (in North)	~~~	~~~	Kuttung Series	

The wavy line denotes a *disconformity* or *unconformity*.

passes up into a group of hard shales, flagstones, and sandstones with *Glossopteris*, etc., like those described from the Falklands. *Eurydesma* is present above the glacials. In San Juan district glacials resting on striated floors are in one place overlain by marine Upper Carboniferous with *Spirifer* and *Productus*,[1] and in another include layers with *Cardiopteris* and *Rhacopteris*, indicating the *Middle Carboniferous* at least.

So astonishing are the resemblances, stratigraphical, lithological and tectonic, of the formations from the Devonian onwards in the Cape, Falklands, and Argentina, that they have led to the idea of the actual disruption of the western section of Gondwanaland into two main portions now parted by the Atlantic, a hypothesis that receives remarkable support from the facies of the corresponding strata in Uruguay, Paraguay, and southern Brazil. Just as to the north of Karroo Poort in the Cape the Dwyka tillite transgresses over the Cape System on to the pre-Cape formations, so in Paraná the glacial beds overlap the Devonian formations and pass on to pre-Devonian rocks. Furthermore, the facies of the Gondwana beds, here known as the Santa Caterina System,[2] recalls characters found north of the Karroo, in South-West Africa, and the Transvaal.[3]

Resting unconformably and horizontally on older rocks, at a few points at least—probably elsewhere too—on a striated floor, are the thick Itararé boulder-beds, which are not only compound, but may have a "red tillite" below and a "blue-green tillite" above exactly as in South-West Africa, and with corresponding direction of ice-flow.[4] Four advances of the ice are shown by the intercalated sediments, in part marine. They are succeeded by the grits, sandstones, and shales of the Rio Bonito beds and these by the Iratí beds with a zone of carbonaceous shales containing *Mesosaurus*, manifestly the equivalent of the White Band. The Rio Bonito group contains coal and has yielded an abundant flora including *Gangamopteris*, *Glossopteris*, *Lepidodendron*, *Sigillaria*, etc., strikingly like that of the Ecca Series.

[1] A. Heim, *Rev. Mus. La Plata*, Sec. Geol. II, 1945, 267; O. Bracaccini, *Bol. Informaciones Petroleras*, 1946.

[2] See A. I. de Oliveira and O. H. Leonardos, *Geologia do Brasil*, 1943, ch. xi-xiv.

[3] A. L. du Toit, *Carnegie Inst.*, 1927, Publ. 381; R. Maack, *Zeit. Ges. Erdk. Berlin*, 1937 (Ergänzungsheft v.).

[4] V. Leinz, *Neu. Jahr. f. Min.*, etc., B-Bd., 79, 1938, B, 26; R. Maack, *Arquivos do Museu Paranaense*, v, 1946.

It should be noted, though, that in South America this plant-bearing stage lies below the zone of *Mesosaurus*, in South Africa above the latter. The Rio Bonito beds will consequently have to be the fluviatile equivalent of the Upper Dwyka shales.

The few fossils in the succeeding Estrada Nova, such as *Leaia*, suggest a Permian age. A break involving much of the Upper Permian and Lower Triassic is indicated by a scanty fauna with *Pachycardia*, *Myophoria*, etc., apparently of *Upper Triassic age*, in the Teresina beds, marking a short marine incursion, one not yet recorded from South Africa. The higher-lying Rio do Rasto beds contain brilliant red and purple mudstones and sandstones and pass up through false-bedded red-brown sandstones of æolian origin into the massive paler Botucaú Standstone, covered by the basaltic lavas that occupy such an enormous region in Paraná, Santa Caterina, Paraguay, etc. The presence in the Santa Maria of allied reptilian forms such as *Dicynodon*, *Stahleckeria*, and *Scaphonyx* serves to correlate them with the Upper Beaufort-Red Beds succession, while the succeeding groups can on lithological grounds be compared with the Cave Sandstone and the Drakensberg Volcanics respectively.

In south-western Madagascar the glacial conglomerate of the Onilahy Valley is succeeded by strata with coal, *Gangamopteris* and *Glossopteris* and by red conglomerates, sandstones, and limestones with *Productus*, *Spirifer*, *Xenaspis*, etc., indicating the lowest Upper Permian.

In India the basement glacial boulder-bed of the Salt Range is overlain by the olive shales and sandstones with *Eurydesma*, *Conularia*, and *Gangamopteris*, the description thereof recalling the succession in South-West Africa, followed (after a palæontological break) by the marine Lower Productus Limestone, almost universally accepted as not younger than Lower Permian. Holland,[1] reviewing the evidence, has favoured a pre-Permian age for at least the boulder-bed.

Peninsular India can show the Talchir boulder-bed resting in places on striated floors, followed by unfossiliferous shales, and these overlain by the plant-bearing division of that Series, and above by the Karharbari stage with coal seams and numerous remains of plants. Fox[2] holds that the boulder-bed represents merely the *closing stage* of a lengthy glaciation.

[1] T. H. Holland, *Q.J.G.S.*, 1933, lxxxix, p. lxiv.
[2] C. S. Fox, *Mem. G.S. India*, 1931, lviii.

Illuminating comparisons can be made with Australia, though there are still differences of opinion as to where the boundary should be drawn between Carboniferous and Permian.

In Western Australia thick dominantly marine assemblages are widely developed with glacials at their base, followed by beds with an abundant fauna of Lower Permian age in which occur horizons containing *Glossopteris*, *Lepidodendron*, etc.[1] While the faunal affinities are with India, *Eurydesma* has not yet been recorded.

In the Hunter River area in New South Wales the thick succession starts well down in the Carboniferous and passes up into the Kuttung Series of conglomerates, fluvio-glacials, tillites and varve shales with *Rhacopteris* and *Cardiopteris* that denote a high stage in the Lower Carboniferous, followed by the Lochinvar glacials, the sandstone with *Gangamopteris* and beds with *Eurydesma* that constitute the Lower Marine Series of the Kamilaroi System. Above come the Greta Coal Measures with Glossopteris Flora and the Upper Marine Series. Fluvio-glacials or bands carrying erratics occur on widely-spaced horizons in the Lower and Upper Marines, the youngest of which is ascribable to the Middle Permian. David and Sussmilch place all the strata below the *Eurydesma* horizon in the Upper Carboniferous, though others would set the boundary lower. The main glacials, resting usually on finely-striated floors, are represented in Tasmania, Victoria, and South Australia, the direction of the ice-flow being from south to north generally.

Like that of the other parts of Gondwanaland the glaciation of South Africa must have been multiple and lengthy. In Argentina and New South Wales it had commenced before the close of the Lower Carboniferous, while in all the countries concerned the major phase was waning, if it had not ceased, by the earliest Permian. The several phases of the Dwyka Ice age must therefore have embraced much, if not the whole, of the *Upper Carboniferous*, while the Upper Dwyka shales (with *Eurydesma*) can be viewed as not younger than *Lowest Permian* and the Ecca Series as *Lower Permian*. The extraordinarily persistent nature of the Upper Ecca shales from Pondoland to Nyasaland prompts the suggestion of their equivalence with the " Ironstone Shales " forming the middle division of the Damuda of India.

[1] D. D. Condit, H. G. Raggatt, and E. A. Rudd, *Bull. Amer. Assn. Petr. Geol.*, 1936, xx, 1028; C. Teichert, *ibid.*, 1941, xxv, 371.

Considering the Lower Beaufort beds, valuable evidence comes from Russia, where pareiasaurian and other reptiles occur along with *Palæomutela* and *Palæanodonta* in a zone of fresh-water deposits underlain and overlain by marls and sandstones containing marine species of Zechstein age on the Dvina River in the north [1] and also along the middle Volga, whence the Endothiodon-Cistecephalus zones must be viewed as of *Upper Permian age* (p. 292). Incidentally, the long-asserted existence of associated examples of the Glossopteris Flora has to be doubted, since some at least of such Russian types have been incorrectly identified with Southern forms.

The flora of the Lower Beaufort is very like that of the Newcastle stage of New South Wales and the Raniganj stage—the upper part of the Damuda Series of India—groups which from other lines of evidence are clearly Upper Permian.

The Middle Beaufort is apparently homotaxial with the Panchet stage of India, which contains *Dicynodon* and *Lystrosaurus*, and the Narrabeen stage of the Hawkesbury of New South Wales and can be considered as *Lower Triassic*. The Upper Beaufort can be compared with the Maleri stage of India and with the Hawkesbury Sandstone [2] of New South Wales, the labyrinthodonts and fishes of which confer a *Middle Triassic age* (see p. 341). *Hyperodapedon* from the first-named is allied to *Mesosuchus* and *Howesia*.

The Sakamena Series of Madagascar—the equivalent of the Beaufort—includes successive horizons with (*a*) *Pteria*, (*b*) *Glossopteris*, *Voltzia*, etc., (*c*) the reptile *Tangasaurus*, (*d*) *Rhinesuchus*, and (*e*) Upper Triassic ammonites.[3]

The flora of the Molteno beds is surprisingly like those of the so-called "Rhætic" of Argentina, Tonking and New Zealand, the Jerusalem Beds of Tasmania, Ipswich of Queensland, and Wianamatta of New South Wales. The presence in the latter of the Keuper labyrinthodont *Cyclotosaurus* and of the various fishes is support for the Upper Triassic age of this flora in Australia, while in South Africa this is substantiated both by the plants themselves and by the fact that the fauna of the succeeding Red Beds and Cave Sandstone is undoubtedly not later than Rhætic,

[1] V. Amalitzky, *Geol. Mag. for* 1901, 201, 231; S. H. Haughton, *XV Inter. Geol. Congr.*, 1930, ii, 252; J. A. Efremov, *C.R. Acad. Sci. U.S.S.R.*, 1937, xvi, 121.

[2] C. A. Sussmilch, *Geology of New South Wales*, 1914, 2nd. Ed., chap. xi.

[3] H. Besairie, *Mem. Acad. Malgache*, 1936, xxxi, 35.

there being no evidence directly opposed to such a view in the other five countries just referred to. The Indian representative seems to be the Parsora stage with *Dicroïdium*, *Danæopsis*, etc.

From this it would appear that the Volcanic group forming the summit of the Karroo will be of *Rhætic or at the latest of Liassic age*, a view supported by the presence of *Otozamites* in a sedimentary band, and confirmed from north-western Madagascar, where the persistent Isalo Sandstone, the lithological equivalent of the Cave Sandstone, contains *Myophoria* in places and is followed by a marine Upper Liassic horizon. In Brazil the succession also ends with the basalts, but in western Argentina the volcanics are overlain by marine Lias or Dogger. Comparison can also be instituted with the Rajmahal stage of India, a group of basaltic lavas with some interstratified beds that have yielded a flora of Liassic affinities.

Refocussing attention on the African continent, the triple division of the Karroo seen at the head of Lake Nyasa is found at several places between there and Tanga on the coast, *i.e.* a basal group of grits and conglomerates, a middle one of shaly beds and an upper one of sandstones, etc. The dark shales have furnished in various places, but doubtless on different horizons, *Glossopteris*, *Voltziopsis*, *Palæanodonta*, *Palæomutela*, *Anthracosia*, and sometimes reptiles, such as *Dicynodon*, *Endothiodon*, and *Rhinesuchus*, denoting the middle of the Lower Beaufort Series.[1] Recent discoveries include *Bradysaurus*, *Megacyclops*, *Lystrosaurus*, *Kannemeyeria*, and *Trirachodon* (Boonstra). A marine fauna from the Kidodi area with *Gervillia*, *Liebea*, *Modiolopsis*, and *Pteria* of uppermost Permian age[2] forms a link with a similar one from the Sakamena beds of Madagascar. The volcanics are absent north of the Shiré area, while west of Mombasa the uppermost Karroo strata pass beneath unconformable marine Jurassic (Bathonian) Beds.

Glacials corresponding with those of the Dwyka occur in Angola and in eastern Congo,[3] *e.g.* in the Lukuga Valley west of Lake Tanganyika and again to the north around Walikali, where they rest on striated floors and are overlain by coal-bearing strata with *Gangamopteris*, and hence of Ecca age. The Stanleyville

[1] See F. Behrend, *Beit. geol. Erfor. Deuts. Schut.*, 1918, Heft. 15; F. Dixey. *XV Inter. Geol. Congr.*, 1930, ii, 143; S. H. Haughton, *Q.J.G.S.*, 1932, lxxxviii, 634.

[2] G. M. Stockley and L. R. Cox, *Q.J.G.S.*, 1936, xcii, 1.

[3] See A. C. Veatch, "Evolution of the Congo Basin," *Geol. Soc. Amer.*, 1935, Mem. 3.

beds of the Lualaba-Congo River follow—clays, grits, sandstones, and limestones with fish and crustacean remains, *e.g. Pholidophorus*, *Peltopleurus*, and *Estheriella*—that represent the Middle or early Upper Beaufort. Transgressing unconformably across the latter on to the crystallines and covering an enormous region is the Lubilash (Lubilache)—thick reddish to white friable sandstones and conglomerates with some red shales containing Estheriæ of Triassic affinities, thereby correlating that formation with the Stormberg Series.[1]

[1] S. H. Haughton, *Ann. S.A. Mus.*, 1924, xii, 460.

CHAPTER XIV

THE KARROO DOLERITES

General. Distribution. Forms Assumed. Sheets. Dykes. Petrological Characters. Differentiation. Syntectic Phenomena. Metamorphic Effects. Alteration of Coal Seams. Weathering. Relation to Stormberg Volcanicity. Age. Economic Aspect.

General.—The dark-coloured crystalline igneous rock, which is so conspicuous right through the Karroo region, Orange Free State, and Natal, has fittingly been called "*Karroo Dolerite,*" while to the Afrikaans farmers it is known as "Ysterklip" (Ironstone), in part because of its weight and rusty appearance when weathered, in part because of the metallic sound given out when struck with a hammer.

Occurring as it does over a truly enormous area in South Africa, a conspicuous feature is its constant association with strata belonging to the Karroo System, into which it is *intrusive.* Indeed, the extent of this "*Karroo Magma Province*" may be far wider than supposed.

Distribution.—The dolerites have avoided the southern and western folded belts of the Cape, their approximate limits in these directions being made by a line drawn through Nieuwhoudtville, the Tanqua Karroo, Beaufort West, Aberdeen, Somerset East, Fort Beaufort, and East London. The many isolated dykes to the south-west, as in the Cape Peninsula, are on petrographical grounds regarded as older.[1] To the north-east of this line they are ubiquitous within the Karroo beds as far east as the Lebombo, becoming fewer towards the north.

North of the Orange River the Karroo System in the triangular area between Upington, Gibeon, and the Richtersveld is considerably invaded by dolerite. Farther to the north-west along the Atlantic coast, and again inland south of Lake Ngami, many narrow dykes occur dating apparently to this period. Southern Rhodesia and the northern Transvaal are fairly free from dolerite except in the south-eastern corner of the former, where intrusions abound in the Melsetter-Chipinga area and the adjacent Territory

[1] *Ann. Univ. Stellenbosch,* 1944, xxii, sect. A, 27-62.

of Moçambique, penetrating the beds of the Umkondo Series chiefly. They are, however, well developed within the Zambezi trough, particularly about Tete, and range northwards into Nyasaland, again intrusive mainly into Karroo beds.

In addition to this huge area affected in South Africa, a truly vast region was simultaneously invaded by basic matter in other parts of the ancient "Gondwanaland," in Brazil, Antarctica, and Tasmania.

Forms Assumed.[1]—The innumerable intrusions occur in one or other of the two following forms, (1) *Horizontal or inclined sheets or sills* of extremely varying thickness, or (2) *Narrow vertical dykes*. The first-named predominates.

(1) *Sheets.—Horizontal sheets* follow more or less concordantly the bedding planes of the invaded strata, particularly along horizons where the beds were easily split apart; good examples appear along the northern Karroo and in South-West Africa. Thus the lowest sheet north of Hopetown must have been continuous over at least 5000 square miles. Another important sheet follows a horizon a couple of hundred feet above the coals in the area between Vereeniging, Villiers, Greylingstad, and Standerton.

Through the hard nature of the rock a sheet frequently comes to cap higher ground and give rise to a plateau, as at Helpmekaar in Natal or, in the more dissected stage thereof, to detached flat-topped hills, *e.g.* Tafel Berg near Rosmead and the Rhenoster Berg near De Aar. Owing to an inherent tendency towards the development of columnar structure in the sheet, the scarps commonly form a "palisade," as for instance in the bare precipices crowning the Nieuweveld (Nuweveld) at Beaufort West, or they produce wonderfully jointed pillars as in the Valley of Desolation near Graaff Reinet.

The majority of sheets are, however, *inclined* and transgress across the bedding-planes, dips of from 15 to 50 degrees being most common, but there is often much variation in the dip and strike of each individual intrusion. Their outcrops tend to produce chains of hills that rise above the flatter ground built of sediments and to these dolerite intrusions is due almost wholly the diversity in relief of the northern Karroo and of the western and southern parts of the Orange Free State. In the Queenstown and Glen Grey districts the very regularly undulating behaviour of a thick sheet over an area of a few thousand square miles has upon erosion

[1] See A. L. du Toit, "The Karroo Dolerites," *T.G.S.S.A.*, 1920, xxiii, 1.

given rise to crater-like features from five to ten miles across, an impressive example forming the Bongolo Valley at Queenstown. These curious " rings " have been noted elsewhere, as at De Aar (Plate XXXIV, 1), Britstown, and in East Griqualand.

Speaking very generally the sheets range from 50 to 500 feet in thickness, but far thicker bodies or " pods " are known in the Eastern Province of the Cape, Transkei, and southern Natal, ranging from 1000 to over 2000 feet. Though some have been referred to as laccolithic bodies, the invaded strata have not been arched upwards over them as in the typical laccolith, but only slightly tilted in places. In the remarkable body seven miles by four forming Mount Arthur (East Griqualand) [1] enormous masses of strata detached from its roof sank deeply into the intruding magma.

Viewed in the mass the dolerites are seen to ramify through the beds in an amazing manner and, where cutting obliquely through the latter, the strata above are found to have been raised relatively to those below the sheet; in the case of the thicker intrusions such displacement may amount to several hundreds of feet. The term " fault-dolerite " may be used in such cases. Tilting of the beds is generally absent, save just alongside the largest intrusions, a fortunate circumstance in the Natal Coalfields where the seams have so frequently been broken through and dislocated by sills. Successive sheets may occur one above the other, as reference to Fig. 37 will show. That they could be due to repeated injections is indicated by marked petrological differences though direct proof thereof is not always forthcoming. Over a wide area in Vryheid at least *seven injection-periods* have been proved by actual intrusive contacts, mostly chilled.[2] In the Paardekop sill, district Volksrust,[3] there is a hint of more than one heave of magma producing the intrusion. There are commonly two or three such sills in every thousand feet of Karroo beds, while over large areas in the east the proportion of igneous to sedimentary rock certainly exceeds one-sixth.

(2) *Dykes.*—In addition to highly-inclined bodies, which thereby assume a dyke-like habit through a limited vertical range,

[1] A. Poldervaart, *T.R.S.S.A.*, 1946, xxxi, 83-110.

[2] J. J. G. Blignaut and F. J. J. Furter, *Union S.A.G.S.*, 1940, Coal Mem. 1, 71-3.

[3] A. M. J. de Swardt and L. J. Murray, *Ann. Univ. Stellenbosch*, 1944, xxii, Sect. A, 1-26.

1.—Dolerite Sill at De Aar : a partial view of a " ring-shaped intrusion " dipping from left to right beneath the central area occupied by Ecca shales.

2.—Dyke of Granophyre (light-coloured) traversing a thick sheet of dolerite near mouth of Kobongaba River, Kentani, Cape.

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there are multitudes of narrow vertical intrusions from 6 to 30 feet in breadth, which run in sinuous or straight lines for long distances. From 5 to 20 miles is a common length, but some have been followed for over 50 miles and the two wide " Gap Dykes " of the Transkei for nearly 100 miles. Along them limited faulting may be present. Some merge with the dolerite of the sheets, but others cut the latter and so prove the *slightly later age of the dyke-irruption.* They may differ petrographically [1] and even cut one another. They produce low ridges but, where ill-exposed, may only be traced when they traverse sandstone ledges or stand revealed by a line of vegetation along them.

Striking are the parallel, east-west, " *Gap Dykes* " to the north of East London, that have been traced for nearly 100 miles, from the coast near Mazeppa Bay to just south of Cathcart, diverging slightly and dying out in that quarter. Averaging from 600 to 900 feet wide and cutting through sediments and dolerite sheets alike, they are composed of coarse-grained gabbroidal rock which, through ready weathering, has been eroded into longitudinal valleys.[2]

Varying appreciably in composition and texture in different parts, the rock is normally olivine-free and composed of labradorite feldspar, reddish biotite, and clinopyroxene, the latter partly converted into brown hornblende (Plate XXXV, 2). Having a silica percentage of 50-52 (Analysis No. 57), the name " *dolerite-pegmatite* " is more fitting than " diorite," as originally stated. By Mountain these dykes are viewed as derived from a contaminated dolerite magma.

Within and around Basutoland and in the Waterberg-Tuli region the trend of the dykes is mostly west-north-west with a poorer developed complementary set at right angles thereto ; in the eastern Transvaal north-east ; along the Lebombo and western Karroo north-south ; in the Namib region about Swakopmund and along Lake Ngami north-east and east-north-east.

They are poorly represented to the east of a line drawn from near Umtata through Mount Ayliff, Dundee, and Piet Retief, although sheets remain as numerous as ever in the Karroo strata. In the harder and less fissile pre-Karroo formations sheets are uncommon, but narrow dykes occur, which probably constitute the feeders from which the thicker intrusions of the higher horizons were derived.

Narrow and irregular pale grey acid veins and dykes, often only a

[1] J. J. Frankel, *T.G.S.S.A.*, 1943, xlv, 1-25 ; 1944, xlvi, 47-53.

[2] A. W. Rogers and E. H. L. Schwarz, *T.S.A.P.S.*, 1904, xiv, 66-75 ; F. Walker, *T.R.S.S.A.*, 1943, xxx, 79-83 ; E. D. Mountain, *T.G.S.S.A.*, 1944, xlvi, 55-73.

few feet or inches wide, approximating in composition to diorite or even to micro-granite or granophyre, traverse the thicker sheets now and again. Some have been formed by the solidifying within contraction-rifts of the siliceous residue left over from the crystallising of the dolerite ; others by the syntexis of sandstone or siltstone, as is asserted by Mountain [1] for that figured in Plate XXXV, 2.

(3) *Acid Intrusions.*—In eastern Swaziland there are two important large bodies, one of which, a full mile wide, crossing into the Transvaal, builds the Mananga Mountain, is dyke-like and composed of augite granophyre and unusually rich in disseminated magnetite.[2] Similar granophyres cutting the basalts occupy a wide area between the Bubye and Sabi rivers in the south-east of Rhodesia, and are again seen at Cape Cross north of Swakopmund, while large plugs of related granite pierce presumed Karroo volcanics in the Erongo Mountains, Brandberg, and Messum.

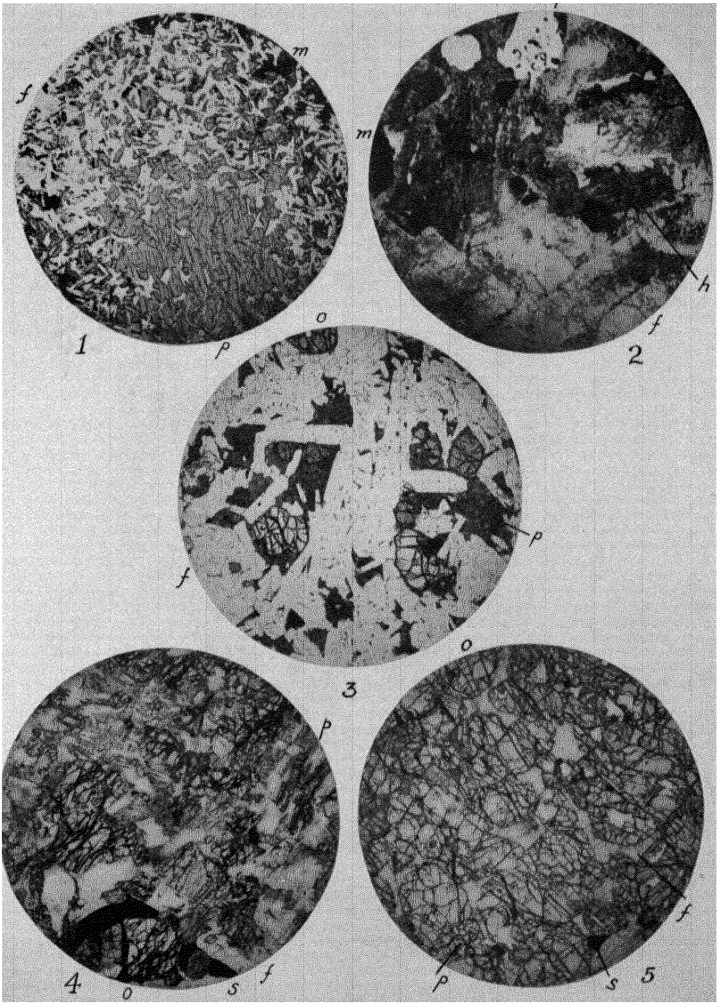
Petrological Characters.—According to current nomenclature the Dolerites, which are composed chiefly of plagioclase and augite in about equal volumes (43-44 per cent.), ought to be referred to as Diabase ; but the name *Dolerite*—following the classification of Allport and Teall—has become firmly established in this country and its retention is particularly desirable, since this kind of rock is thereby satisfactorily distinguished from the various older and commonly altered basic intrusions, which are consistently styled *Diabase.* In turn they are divisible into the two principal types, the olivine-poor or olivine-free *Tholeiites*, and the *Olivine dolerites* (Analyses Nos. 51 and 50).

In the thinner sheets and in the dykes the texture is usually *porphyritic*, the crystals of plagioclase, pyroxene, and olivine being embedded in a fine-grained matrix or mesostasis of pyroxene granules and feldspar microlites, sometimes with a little brownish glass. At the margins of the intrusions the texture becomes finer and occasionally a very narrow selvedge of black stony *tachylite* is found, which under the microscope will show small porphyritic crystals set in a dense yellow or brown glass, perhaps containing *spherulites.* Spherulitic dolerite has been described from Vryheid (Campbell Smith).

In the thicker bodies the rock is greyer and coarse-grained with a specific gravity of between 2·95 and 3·05. In thin section it shows (Plate XXXV, 1) laths of labradorite feldspar disposed within large irregular crystals of pale greenish pyroxene in the manner known as *ophitic*, while olivine may be present, always in small grains and slightly serpentinised ; either magnetite or ilmenite is to be seen, also apatite

[1] *loc. cit.* 71.

[2] H. J. R. Way, *Ann. Rep. Geol. Surv. Swaziland* 1945, 23.



Photomicrographs of Rocks belonging to the Karroo Dolerites. 1, Dolerite; 2, Diorite; 3, Norite; 4, Olivine Gabbro; 5, Picrite. *q*, quartz; *f*, plagioclase feldspar; *p*, pyroxene; *h*, hornblende; *o*, olivine; *m*, magnetite; *s*, sulphide ores. All magnified 10 diameters.

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and sometimes a little biotite. Not a few of the dolerites proper show small amounts of interstitial micropegmatite, olivine being absent; quite a number of these can indeed be termed *Quartz dolerites.*

If one includes the thickest bodies, the component minerals are found to vary appreciably in their composition as well as proportion. The *Plagioclases* range usually from Anorthite 60-80 per cent. No fewer than four *Pyroxenes* may have crystallised out :—(*a*) Orthopyroxene (bronzite or hypersthene), (*b*) Early Pigeonite (a pyroxene rich in clinoenstatite or clinohypersthene)—usually seen in "cores," (*c*) Augite, and (*d*) Late Pigeonite. Nos. *a* and *b*, and *a* and olivine, are antipathetic. The *Olivine* may range through iron-rich varieties to pure fayalite, as in a sheet at New Amalfi (East Griqualand), and may be altered to bowlingite. *Magnetite* is occasionally high as at New Amalfi and Mount Arthur.

Differentiation.—The vast majority of intrusions consist of ophitic dolerites or of tholeiites derived from a parent magma only slightly less femic than that of the average "plateau basalt" (Analysis No. 50). In certain cases, and particularly in the thickest bodies, there has been marked differentiation following the settlement of early-forming olivine crystals, with development of *Picrite*, as in a sill near Middelburg (Cape) [1] or in the Elephant's Head Dyke (Mount Currie).[2] It must be stressed that such differentiated types appear to form only a small fraction of the amount of intrusive rock in sight within the wide region thus far traversed.

Such a consequence is finely displayed in the thick curving sheets which build up the mountain masses of the Insizwa, Tabankulu, Tonti, and Ingeli in East Griqualand, where sections of from 1000 to over 2000 feet thick stand exposed.[3] They consist mainly of pale, speckled, granite-like rocks that pass laterally into the normal ophitic dolerites of the general network. Composed of interlocking plagioclase, pyroxenes of various kinds and often olivine, they can be termed *Gabbros*, or, when orthorhombic pyroxene is present in any quantity, *Norites* or *Hyperites* (Plate XXXV, 3; Analysis No. 53). The basal "chill-phase" of *Hypersthene gabbro* approximates in composition to that of the average dolerite magma. Above comes a zone marked by fresh idiomorphic olivines, of *Troctolite, Picrite*, etc. (Plate XXXV, 5; Analysis No. 54), which in the Tabankulu and Ingeli is hundreds of feet thick and pseudostratified. Certain varieties carry sulphides of magmatic origin, disseminated through the rock or as irregular veins (see p. 533) (Plate XXXV, 4 and 5). These sulphides crystallised after the silicates

[1] F. Walker and A. Poldervaart, *T.G.S.S.A.*, 1943, xlv, 55-64.

[2] A. Poldervaart, *T.R.S.S.A.*, 1944, xxx, 85-119.

[3] A. L. du Toit, *Ann. Rep. G.C. for* 1910, 111; *Union S.A.G.S. for* 1912, 153. W. H. Goodchild, *Inst. Min. and Met.*, 1916, Bull. 147. D. L. Scholtz, *T.G.S.S.A.*, 1937, xxxix, 81.

and usually in the following order : pyrrhotite, pentlandite, chalcopyrite, and cubanite, as detailed by Scholtz.

The succeeding *Olivine norite* passes up into olivine-free *Norite* and *Gabbro*, and that into a more acid phase carrying micropegmatite and biotite at the top (Analysis No. 55).

The Mount Prospect mass, 1200 feet thick east of Libode in the Transkei, similarly becomes dioritic near its roof. In other instances, however, where an acid phase appears towards the top, or even well within the sheet, it might be due not to differentiation but to syntexis, as discussed below. At Mount Arthur a tholeiitic magma would seem to have been developed through the introduction of volatiles contributed by large sedimentary xenoliths (Poldervaart).

Syntectic Phenomena.—It is becoming clearer that certain paler acid granophyric modifications of dolerite have arisen from the extreme *metasomatism* or *syntexis* of sandstone or mudstone under the influence of the invading basic magma. Once such a hypothesis has been established by the reaction-shells around xenoliths in the intrusion, larger-scale syntexis becomes more manifest, mainly towards the top of the sheet, the boundaries between the reaction-product and the metasomatised sediment being sharp in some places and indefinite in others. In several cases there has been recorded a passage from normal dolerite to a granophyre having about 66 per cent. of silica, with andesine feldspar and micropegmatite, through a transitional "contaminated" coarse type termed "*Dolerite-pegmatite*," as for example at Hangnest, Alewyns Gat, and Rietkop in Calvinia,[1] New Amalfi in East Griqualand,[2] and Gonubie, Ibeka, and Gqunqi in the Transkei,[3] (Plate XXXV, 2). Analyses Nos. 56 and 57 apply to a granophyre and a dolerite-pegmatite respectively.

Furthermore, the acid product may in turn have been intruded not only into the crystallising dolerite but, though more rarely, into the adjacent sediments, an action termed "*rheomorphic injection.*" Even the transformation of Old Granite into micropegmatite along contacts has been recorded.[4]

All the same, *such cases of syntexis are extremely few* as compared with the host of normal contacts exhibiting no signs of reaction whatever.

[1] F. Walker and A. Poldervaart, *T.G.S.S.A.*, 1941, xliii, 159-173 ; 1942, xliv, 127-148 ; 1943, xlv, 55-64 ; *T.R.S.S.A.*, 1942, xxix, 285-307.

[2] A. Poldervaart, *T.R.S.S.A.*, 1944, xxx, 85-119.

[3] E. D. Mountain, *T.G.S.S.A.*, 1944, xliv, 55-73 ; 1945, xlvii, 107-121.

[4] L. Thornton, *T.G.S.S.A.*, 1931, xxxiii, 31-47.

Metamorphic Effects.—The sediments in contact invariably exhibit a certain amount of alteration, which increases with the thickness or width of the intrusion. Shales and mudstones have been converted into intensely hard *hornstone* or *lydianite*, a black flinty rock, weathering with a thin brownish crust and breaking with a conchoidal fracture, while in the case of the huge gabbro-norite bodies of East Griqualand and Pondoland the sediments nearby have been changed into thoroughly crystalline " porphyroblastic *hornfelses* " containing quartz, cordierite, mica, and sometimes enstatite and showing a granular texture.

Calcareous or dolomitic bands and concretions have given rise to greenish epidote, grossular garnet, vesuvianite, wollastonite, zoisite, etc. With sandstone the product is a quartzite, while in certain instances orthoclase has been developed with a little micropegmatite—a stage indeed towards the formation of granophyre—largely by regeneration of the original feldspars contained in the rock.

Alteration of Coal Seams.—Coal, and to a lesser degree carbonaceous shale, may have experienced loss of hydrocarbons through a sheet of dolerite intruded either below or above it, although the thickness of the intervening strata may have ranged between 100 and 300 feet. Throughout the Natal and the Stormberg coalfields extensive areas of ground are known in which the seams have suffered severely from such invasion. Heslop has indeed reckoned that 90 per cent. of the coals in Natal have been thus affected, more particularly in respect of their coking qualities.

A rough rule is to reckon that, whenever a dolerite sheet approaches to within a distance from the seam about equal to the thickness of the intrusion, the coal will be found affected thereby; a dyke is similarly estimated to have extended its influence to a distance on either side equal to its own width. Such limits have been considerably exceeded, as in the Spitzkop colliery at Ermelo, where a 16-foot dyke has affected the coal to a total width of about 300 feet. All stages are represented in this process, through the semi-anthracitic to the wholly anthracitic condition, as the volatile constituents of the coal have progressively been lost. At the contact with the igneous rock the coal may have been coked and sometimes rendered columnar; at the same time thin intrusive tongues within the seam may

have been converted into the curious pale material known as " white trap." Coal or carbonaceous shales may even be changed to impure graphite as on a large scale on Rustplaats No. 165, Vryheid.

Since the coal and the associated shales constitute horizons of easy separation in the Coal Measures, it is not at all surprising that the magma should so frequently have forced its way along or next to the plane of the seams and thus spoiled the latter. The hydrocarbons generated by such natural distillation of coal or carbonaceous shale must generally have diffused away into the overlying strata, but occasionally they appear to have been condensed in the latter, thereby impregnating those beds with oily or tarry matter. This seems to be the most reasonable explanation of an oil-soaked sandstone found in a borehole near Dannhauser in Natal. At other times the gases were taken up or occluded by the rising magma ; then, as the latter started to solidify, the vapours were set free and condensed as liquid or solid hydrocarbons in the vesicles which were formed in the rock (see Chapter XX, " Petroleum ").

Weathering.—The sheets frequently display a columnar structure, as in the Theebus Mountain near Steynsburg and Donkerhoeks Berg near Sterkstroom. Occasionally a peculiar type of scenery styled " mural weathering " is developed in which masonry-like masses of jointed, but otherwise sound, dolerite rise in mounds from flats composed of rotten crumbly rock. The dioritic varieties are more prone to such behaviour. Marked instances occur at Pampoenpoort on the Carnarvon railway, Rosmead Junction, and near Colesberg Junction. At other times bare curved surfaces are produced through exfoliation, as is well exemplified by a sheet in and around the town of Cradock. Generally a strongly-developed system of cross-jointing influences the dolerite towards its more characteristic manner of spheroidal weathering, so that the intrusions give rise to ridges surfaced by great piles of " boulders." Especially is this the case in the drier regions ; but the degree and the nature of the weathering are intimately bound up with the climate, rainfall, and geographical situation of the place in question.

In the dry western and northern Karroo the rock is broken up chiefly by insolation, and is gradually reduced to rounded or sub-rounded boulders partly covered with a shiny film of deep-brown or black material—principally oxides of iron and manganese ; that portion just beneath the surface becomes rotted,

though not attaining the earthy stage, but is sometimes permeated with carbonate of lime produced from the decomposition of the lime-bearing silicates.

In the Transkei-Natal-Zululand region, with a more abundant rainfall, the dolerite is often decomposed to depths of from 20 to 40 feet and exhibits "cores" of unaltered rock preserved in a drab or even pinkish friable and sometimes earthy and completely decomposed material. Often the lumps projecting through the soil consist of a core of fresh rock surrounded by a few inches of spongy ochreous material, and that in turn by an outer hard limonitic crust possessing a slaggy-like exterior.

The soils in such areas are either deep-red in colour, sometimes brilliantly so, loamy and rather porous, or else deep-black and very clayey, but with a drab sub-soil; the former are more characteristic of slopes, the latter of flats and valley bottoms (see Chapter XIX). Such sedentary soils are invariably more fertile than those derived from the Karroo sediments, for in the first place they contain available lime, magnesia, and a little soda, potash, and phosphorus; in the second, the decomposed rock beneath is more retentive of moisture. Indeed, the position of a dolerite sheet along a hillside can frequently be located by the trees and shrubs thereon, in contrast to the barer slopes composed of sandstones and shales.

Relation to the Stormberg Volcanicity.—The association between the dolerites and the Stormberg basalts is a most intimate one. Basic intrusions are much less numerous in the highest zones of the Karroo System, and in the lavas they consist almost entirely of occasional narrow dykes (p. 302). The evidence from within and around Basutoland goes to show that volcanicity must have commenced with the irruption of the dolerite magma, but that the latter probably continued to force its way through the under-lying Karroo sediments for some time after lavas had ceased to be poured forth at the surface.

As remarked earlier, in the absence of related volcanic pipes like those of the main Basutoland area, it becomes impossible to account for the basic lavas in the Transvaal, Rhodesia, Kalahari, and South-West Africa, unless it be admitted that the narrow dykes must represent the feeders from which magma welled forth and that the eruptions were of the "fissure type." Along the Lebombo the granophyre bodies and associated acid dykes intrusive in the basalts undoubtedly mark the source of the acid material that was poured out to make the

younger group of rhyolitic and dacitic lavas and tuffs composing this range. This pale rock must be regarded in the nature of an acid differentiate from the basic magma that gave rise to the limburgites, basalts, and dolerites.

Age of the Intrusions.—Except that boulders of dolerite have been found in the Lower Cretaceous conglomerates at the Umgazana and Embotyi near Port St Johns, the precise inferior limit to the age of these rocks is unknown. From their intimate relationship to the Stormberg basalts they were apparently intruded at the very commencement of the Jurassic Epoch.

Economic Aspect.—Apart from the existence of small quantities of copper pyrites in the districts of Queenstown and Cathcart, the only occurrence worthy of attention is that near Mount Ayliff, where copper-nickel ores are locally concentrated at the basal contact of the Insizwa gabbro-norite mass (see p. 533). Prehnite is now and again found in the Karroo along joints in the dolerite and sometimes carries traces of gold.

The influence of these intrusions upon the circulation of underground water makes them of immense importance in this connection (see p. 550), while they furnish a hard, dark building stone and an excellent ballast for railways and roads.

CHAPTER XV

THE CRETACEOUS SYSTEM

Introduction. Neocomian-Wealden. Subdivisions. Age. Areas in the Cape. Neocomian of Pondoland. Lower Cretaceous of Lower Zambezi. Aptian. Albian-Cenomanian. Senonian. Danian. Non-marine Upper Cretaceous. Volcanic Rocks.

Introductory.—Beds belonging to various stages of the Cretaceous, as proved in most instances by their fossils, are represented in the extreme south and south-east of the African Peninsula, occurring along the coast, though not invariably so. Because of overlapping upon an uneven surface the basal beds may vary in their ages in different localities.

(1) The oldest strata represent the extreme base—WEALDEN-NEOCOMIAN—of the System, constituting the *Uitenhage Series*, which may perhaps not be confined to the Cape Province. They tend to occupy elongated structural basins usually hemmed in by ridges made chiefly of Cape rocks. Resting with unconformity upon eroded Cape and Karroo beds, they generally commence with fluvatile conglomerates and pass upwards, where the sequence is complete, through estuarine deposits into marine phases.

(2) An almost complete succession from NEOCOMIAN to SENONIAN—with possible exception of the Turonian—is exposed in Zululand along the Umsinene and Munyuana (Manuan) rivers east of Hluhluwe Station, resting on the Lebombo Rhyolites and dipping at a few degrees eastwards down to the shore of False Bay. Six main groups have been delimited by van Hoepen and, when the thousands of fossils collected already have been worked up, they should provide an outstanding record of molluscan evolution hereabouts.

(3) Elsewhere various stages from APTIAN to DANIAN show themselves at intervals, either fringing the coasts of Pondoland and Natal or along rivers traversing the inner portion of the wide sand- and bush-covered coastal plain of Zululand and Portuguese East Africa, best exposed at the base of the Lebombo Range. In the seaward portion such Cretaceous passes below Tertiary and Quaternary marine beds also heavily masked by sand. The

borehole 872 feet deep drilled at Lake Nhangela, near Inhambane, in 1908 is stated to have pierced the Cretaceous and to have struck some bitumen.

The *post-Neocomian* marine formations show lithological similarities, namely buff or grey sandy clays and soft or gritty sandstones with bands of hard shelly limestone and occasional conglomerate, indicative of shallow water. The geographical conditions changed but little apparently during that prolonged period.

(4) Along the Atlantic coast marine Cretaceous is only known from a tiny patch a little to the south of Lüderitz.[1] The discovery in Namaqualand of dinosaurian bones has proved the existence there of uppermost Cretaceous of continental type (p. 408).

The following Table summarises the classification of the Cretaceous System in South Africa :—

Upper	Danian	Montian	Sheringoma (Portuguese East Africa) and Needs Camp (Cape).
		Maestrichtian	Incomanini (P.E.A.), False Bay (Zululand), Natal, Umzamba (Pondoland).
	Senonian	Campanian	
		Santonian	Umkwelane Hill and Umsinene (Zululand).
		Coniacian	Umsinene.
	Turonian . . .		(Doubtful).
	Cenomanian . . .		Catuane (P.E.A.), Pongola (Zululand), Umsinene, Manuan Creek (Zululand).
	Albian . . .		
Lower	Aptian		Delagoa Bay and Catuane (P.E.A.), Pongola.
	Neocomian-Wealden .		Uitenhage Series, Umgazana and Embotyi (Pondoland), Lower Zambezi.

Crustal Movements and Volcanicity.—The Cretaceous being marked all over the globe by crustal disturbances, it is not surprising to find that during this epoch considerable *tectonic movements* took place along the margin of the African continent and extensive faulting around its shores. It is not unlikely that about this time the numerous volcanic pipes came into being that are filled with kimberlite or other associated eruptive material.

Alkaline igneous rocks occur in Portuguese East Africa, which probably date some to the beginning and some to the close of this epoch, constituting the southernmost representatives of the volcanic suite that plays so important a part in the Great Rift Valley region of Central Africa; they are dealt with at the close of this chapter, together with those from South-West Africa.

I. The Wealden-Neocomian Stage

(1) The Uitenhage Series

General.—Although the beds and fossils of the type area had long been known, having been classified by Atherstone as early as

[1] S. H. Haughton, *T.R.S.S.A.*, 1930, xviii, 361.

1854, the name " Uitenhage Beds " was introduced only in 1867 by Ralph Tate. Strata of similar age, as shown by their lithological characters, and in certain instances by their fossil remains, occur elsewhere, nearly always occupying valleys, namely along the Lower Gamtoos River, up Baviaans Kloof, down the Olifants River between Uniondale and Calitzdorp, in the Knysna and Mossel Bay districts, at Riversdale and Heidelberg, and between Ashton and Worcester. Patches on the coast near Port St Johns have also been relegated to this stage.

(*a*) *The pre-Cretaceous Topography.*—At the close of the Jurassic Epoch three mountain chains ran south-eastwards out to sea, namely the Little Winterhoek-Zuurberg in the north, the Great Winterhoek in the middle and the Elandsberg in the south, each composed of folded Table Mountain sandstone. The valleys in between were eroded in the Bokkeveld slates, the most important one being the northern trough that stretched westwards to beyond Steytlerville.

In the hollows thus constituted sediments were laid down, fresh-water to start with, but becoming estuarine and finally marine as the continent sank and the Cretaceous ocean invaded the valleys from the east. This pre-Cretaceous landscape was quite as rugged as the present one, and the basal beds of the Cretaceous hence came to rest with very marked discordance upon a surface of most uneven character, and often to lap out against ridges of the older rocks (Fig. 54). Indeed, in places peaks of the latter—for example, the Coega Kop—project through the covering of Mesozoic strata, just as the Island of St Croix near at hand stands out from the ocean.

(*b*) *Variable Character of the Deposits.*—Within a region of that nature conglomerates could have been in course of deposition at one spot, while at the same time sands or silts were being spread out not far off. Moreover, in one trough the sediments might have been wholly alluvial in their nature, while in a contiguous one material was being laid down in an arm of the sea. Not only are the lower stages apt to be unrepresented where the land surface stood highest and remained unsubmerged till the last, but there are marked variations in facies from point to point.

(*c*) *Subdivisions.*—Despite the lithological variability the original classification of 1854 by Atherstone still holds good ; the deviations therefrom are discussed later :—

(3) Sundays River Beds.
(2) Variegated Marls and Wood Beds.
(1) Enon Beds or " Enon Conglomerate."

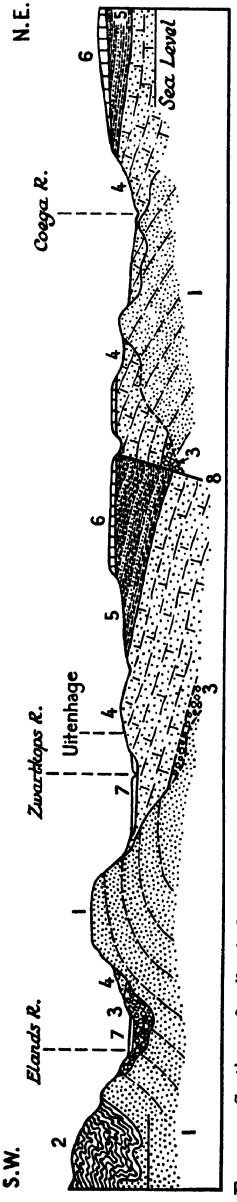


FIG. 54.—Section, 18 miles in length, through the edge of the "Basin" at Uitenhage. 1, Table Mountain Sandstone; 2, Bokkeveld Slates; 3, Enon Beds; 4, Variegated Marls; 5, Sundays River Beds; 6, Alexandria Beds; 7, Alluvium; 8, Coega Fault.

(1) ENON BEDS.—Named after the Enon Mission beneath the Zuurberg (Suurberg), this is certainly the most striking formation in the south of the Cape. Crammed with pebbles and boulders, phenomenally unbedded and massive, yellow or brilliantly red in colour, it produces the most remarkable of hills, curiously carved into crags and hollows in some parts but scrub-covered or pebble-strewn in others (Fig. 55). The inclusions range up to a couple of feet across in exceptional cases, are mostly rounded or sub-angular and mainly of Cape rocks —quartzites and sandstones chiefly. They are packed closely together and have not infrequently been cracked or indented through subsequent earth movements. Gravelly washes and gritty and sandy layers, partings, or lenses are common, sometimes streaks or pockets of red clay; these reveal the stratification. A thickness of between 500 and 1000 feet is frequent, but in places the latter figure is greatly exceeded.

(2) VARIEGATED MARLS AND WOOD BEDS.—The latter consist of soft yellow sandstones and greenish clays with occasional pebbly bands; they contain much fossil wood and occasionally plant remains. They pass laterally as well as downwards into the former group—maroon, red, pink, blue, and grey poorly bedded sandy clays with bands and seams of yellow soft sandstone. The term "marl" introduced by Atherstone is actually a misnomer, since the clays are not appreciably

calcareous. The plants include ferns such as *Onychiopsis* and *Cladophlebis*, cycads such as *Cycadolepis*, *Zamites*, and *Nilssonia* and conifers such as *Brachyphyllum* (Fig. 56). The thickness is from 1000 to 2500 feet, possibly more in places.

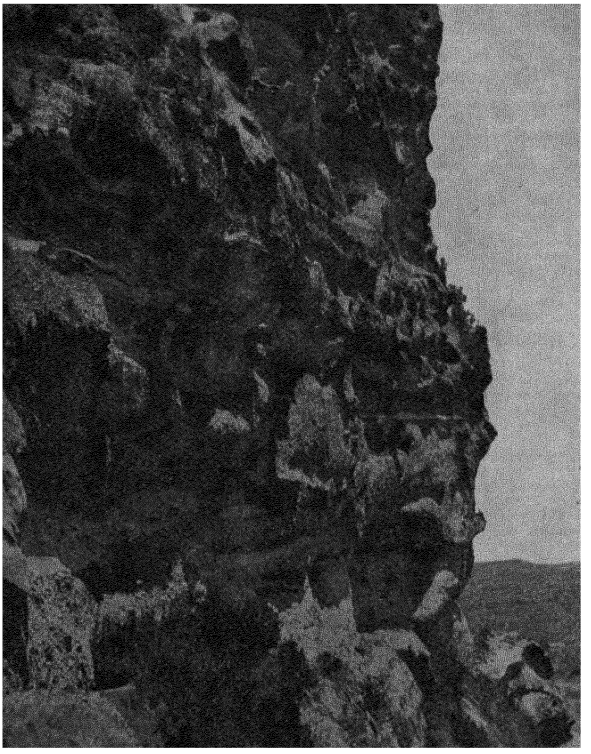


FIG. 55.—Cliffs of small-pebbled Enon Conglomerate, Hankey, Gamtoos Valley, showing the typical mode of weathering.

(3) SUNDAYS RIVER BEDS.—Blue and grey clays, shales, and sandy limestones predominate, with occasional thin greenish sandstones, to a maximum thickness of about 1000 feet. Marine fossils are abundant, of which the commonest are :—Lamellibranchs—*Astarte*, *Exogyra*, *Gervillia*, *Meretrix*, *Modiola*, *Pecten*, *Pinna*, *Pleuromya*, *Mytilus*, *Cyprina*, and various species of

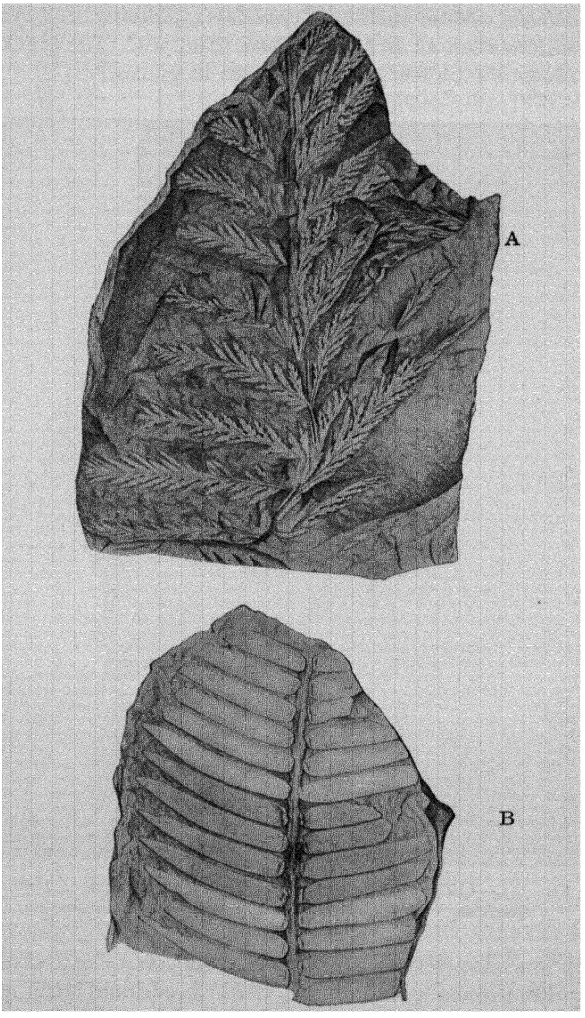


FIG. 56.—Plants from the Wood Beds of the Uitenhage Series. A, *Onychiopsis mantelli*. B, *Zamites recta*. (*After* Seward.)

Trigonia; gasteropods—*Actæonina*, *Natica*, *Turbo*, and *Turritella*; and cephalopods—*Belemnites*, *Hamites*, *Hoplites*, and several species of the ammonite *Rogersites* (*Holcostephanus*) (Fig. 57). The skeleton of a *Plesiosaurus* was dug out of the cliffs of the Zwartkops River overlooking Redhouse.[1]

Away from the type area the Sundays River beds as such are absent, except perhaps at Knysna. The two lower divisions certainly characterise the Oudtshoorn, Gamtoos, and Riversdale-Heidelberg Basins, doubtfully that of Mossel Bay; but the remaining occurrences consist on the other hand of the massive Enon conglomerate, or of alternations of conglomerates and sandstones. These outside areas need more detailed geological work for their elucidation and comparison.

A. The Uitenhage Area[2]

Occupying the lowlands this is 50 miles wide near the coast—as measured from Port Elizabeth to Aluin (Alum) Krans on the Bushmans River—and then westwards for 95 miles before tapering out near the Groot River. In the north the Cretaceous has been thrown down against a west-east fault cutting obliquely across the Cape Fold Ranges but curving southwards in the east. The south-eastern section is concealed by an unconformable covering of marine Tertiary limestones and the structure in that quarter is therefore unknown.

1. *Enon Beds*

Having been so largely dependent upon purely local conditions, these vary considerably in character and thickness from point to point. For instance, hemmed in by ridges of Table Mountain Sandstone, the beds in the upper part of the Zwartkops Valley consist of cream or pinkish pebbly sandstones and conglomerates full of sandstone pebbles. When, however, this same zone is followed up the Elands River Valley, which has been excavated in Bokkeveld beds, it passes laterally into soft deep-reddish rocks crammed with fragments and flakes of blue or grey silvery slate, while in a tributary stream south of the "Cape road" the zone has changed to a hard red conglomerate full of quartzite boulders which is resting on the Bokkeveld slates. This double change

[1] C. W. Andrews, *Ann. S.A. Mus.*, 1911, vii, pt. 4.
[2] *Union S.A.G.S.*, Cape Sheet 9; Sheet 150 and Expln.

has actually taken place within a stretch of not more than five miles.

The dipping of this porous phase beneath the impervious marls furnishes the conditions requisite for an *artesian basin.* Boreholes in the angle formed by the Elands and the Zwartkops rivers close to Uitenhage consequently yield flowing water, while the deep borehole at Zwartkops furnishes a steady output of some 240,000 gallons a day at a pressure of 100 lb. per square inch and at a temperature of 130° F. from this zone, which was cut between 3150 and 3620 feet. Unfortunately the water is charged with bicarbonate of iron, though of great value medicinally. The outcrop waters on the other hand are high in sulphate of iron derived through the oxidation of the marcasite in the sandstones.

The conglomerates are well developed along the northern side of the basin, except where cut out by faulting, as at Sandflats. At Enon, where the pebbles are mostly white quartzite set in a sparse sandy matrix, they give rise to curiously pitted hills, the division probably exceeding 1000 feet in thickness. At Glenconnor, Dwyka conglomerate becomes an important constituent of this rock. From Enon eastwards the dip is southwards at from 20° upwards ; westwards the dips are at first lower, then rise to angles of 50° between Sapkamma and Cockscomb Stations, but flatten out to the south and round the western end of the syncline in the neighbourhood of Eerenkroons Berg. Curiously they are absent on the southern side of the trough, where the Marls, and even the sandstones of the Wood Beds, rest upon a highly irregular surface of Bokkeveld beds ; taken with other evidence this indicates a northern source for the bulk of the material. At a couple of stretches along the Bushmans River Valley, between Mimosa and the Witte River and at the western end of the syncline, the beds rest upon basalts and tuffs of presumed Stormberg age, and the base of the Enon contains debris derived from these volcanic rocks.

2. *Variegated " Marls " and Wood Beds*

The Wood Beds are most fully developed along the northern side of the Kariega River trough, to a thickness of perhaps 3000 feet, embracing sandstones, sandy limestones, thin pebble-conglomerates and grey and blue shales. The best exposures are along the Bezuidenhouts River and the right side of the Sundays River down to Selborne, and again along its left bank over the Dunbrodie Mission lands. Tree trunks, probably coniferous, up to 25 feet long and perforated by the boring mollusc *Gastrochæna,* occur embedded in clayey sandstone.

Proceeding seawards from Bluecliff or Selborne a change of facies takes place—earliest in the lower section—into the red variegated "marls" which pass below the Marine beds. These were not bottomed at 1500 feet in the deep boring at Sandflats. Emerging in the Bushmans River Valley they contain among others inclusions of Karroo sediments and volcanic tuffs, while trunks of trees, all calcified, are abundant. Where they reappear in the Coega River Valley they rest upon a highly irregular, partially buried ridge of Table Mountain Sandstone, peaks of which jut out in places through the clays and sandstones, as in the Coega Kop itself; St Croix and the other islands in Algoa Bay are aligned upon its extension. Traced seawards from Uitenhage—where they follow the Enon—the lower portion loses its red coloration, becoming lavender or greenish, while occasional molluscan remains—such as *Modiola* and *Melania* in addition to *Viviparus* and possibly *Cyrena*—suggest that the beds are acquiring an estuarine character. This portion has in the Zwartkops borehole a thickness of no less than 1725 feet, overlain by 1140 feet of "marls" and those by 217 feet of Marine beds.

The following is a list of the forms hitherto obtained, together with those (x) identified from equivalent beds in other parts of the Cape [1]:—

	Sundays River Valley	Gamtoos River Valley	Herbertsdale.	Umgazana (Pondoland)
Ferns:—				
Onychiopsis mantelli (Brong.)	..	x	..	x
Cladophlebis browniana (Dunk.)	x	x		
,, *denticulata* (Brong.)	x	..	x	
,, sp.	..	..	..	x
Sphenopteris fittoni Sew.	x	x		
Osmundites kolbei Sew.	x	..	x	
Tæniopteris sp.	x	..	x	
Cycads:—				
Zamites recta (Tate)	x	x		
,, *morrisii* (Tate)	x			
,, *africana* (Tate)	x			
Pseudoctenis rubigei (Tate)	x	x		
Nilssonia tatei Sew.	x			
,, sp.	..	..	..	x
Cycadolepis jenkinsiana (Tate)	x	x		
Bucklandia cf. *anomala* (Stokes and Webb)	x			
Benstedia sp.	x			
Carpolithes sp.	x			
Otozamites sp.	..	..	..	x
Dictyozamites sp.	..	x	..	x
Conifers:—				
Araucarites rogersi Sew.	x	?		
Taxites sp.	..	x		
Brachyphyllum sp.	x	x		
Conites sp.	x			
Coniferous woods	x			

[1] A. C. Seward, *Ann. S.A. Mus.*, 1903, iv, pt. 1.

Of the fauna the only mollusc recorded is the fresh-water *Unio*, but certain typical Sundays River species—*Ostrea*, *Perna*, *Pecten*, etc.—discovered hundreds of feet below the top of the division carrying plants, mark a local incursion of the sea.

The chief interest of the Wood Beds lies in the well-preserved leaves in the bluish-grey mudstones and limestones between Paaltjes Kraal (on the Bezuidenhouts River) and the lower portion of the Witte River. Some of these beds are crowded with the broad fronds of *Zamites*, a cycad of which several species have been found ; particularly fine specimens have been gathered from the canal cuttings just above Selborne.

Fossil bones have also been obtained in this division, but invariably as fragments. Under the name of *Algoasaurus baini*, Broom [1] has described a dinosaurian vertebra from the Despatch brick pits near Uitenhage, while Schwarz has discovered portions of a femur of a gigantic dinosaur from the beds on the Bushmans River.

3. *The Sundays River Marine Beds*

Though widely covered by Tertiary limestones or by alluvium and gravels, the exposures along the valleys show these beds to form a broad basin, from Zwartkops almost to Coerney, broken by the Coega fault and traversed by a gentle arch bringing up the Wood Beds between Barkly Bridge and Addo. Dips are rarely more than five degrees, and the highest strata seem to be represented near the Sundays River mouth. The maximum thickness must exceed 1000 feet, for at Redhouse a borehole passed through them at 725 feet. The best sections are in the cliffs along the left of the Zwartkops and along the Sundays River, particularly between Addo and Barkly Bridge (Plate XXXVI), all of which is classic ground, since from those exposures Bain, Atherstone, and Stow obtained their finds more than half a century ago. They must extend southwards to Port Elizabeth, for the drab clays on which are located the three important salt-pans have yielded at the northern end of the Bethelsdorp Pan characteristic species of *Trigonia*, *Exogyra*, *Ptychomya*, and *Cidaris*.

The bulk of the Marine Beds consists of clays, sandy shales, thin impersistent sandstones, and irregularly developed limestones, usually bluish-grey when freshly exposed, hard and crowded with fossils, but weathering yellow or brown. The sandstones are

[1] R. Broom, *Geol. Mag.*, 1904, 445.

Marine Beds (Neocomian), Sundays River below Addo, showing peneplain capped by consolidated gravels probably of Pleistocene age rising about 200 feet above river-bed.

[Face page 380

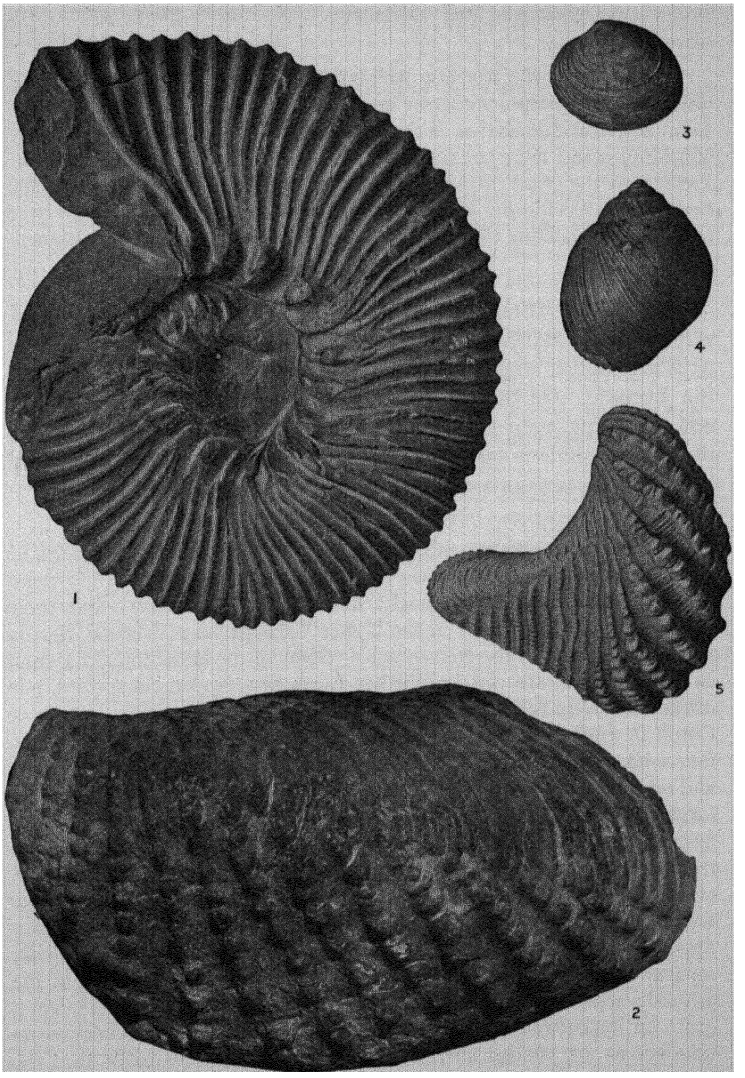


FIG. 57.—Neocomian Fossils from the Sundays River Beds. 1, *Rogersites wilmanæ*; 2, *Trigonia herzogi*; 3, *Meretrix uitenhagensis*; 4, *Natica uitenhagensis*; 5, *Trigonia ventricosa*.

sometimes greenish and saliferous. Red and grey strata are absent.

The softer rocks are not well-laminated nor is there any strong differentiation between coarser and finer material, all of which points to an active accumulation of the muds in shallow water upon a rapidly subsiding ocean floor not far from the shore. In the deep borehole at Zwartkops the great thickness of the estuarine division, deposited very close to sea-level under rather uniform conditions, would seem to bear this out. Supporting this too is the peculiar absence, so far as is known, of *fossil zones*.

Age of the Uitenhage Series.—Doubts have been expressed whether the marine fauna does not embrace more than one palæontological stage and the basal beds do not range down into the Jurassic. On the first point Kitchin [1] has made it clear that, not excluding even the isolated marine zone of the Wood Beds, there is no obvious faunistic change within the strata represented there nor indications of more than *one stage*, namely the *Neocomian*.

In comparing this assemblage with faunas elsewhere, the species of the ammonite genus *Rogersites* (*Holcostephanus*)—unfortunately none too numerous, though of weight in making correlations—find their closest allies among forms in the Upper Valanginian of Europe, that is to say the middle of the Neocomian.[2] Some of the lamellibranchs, such as the Trigoniæ, are closely allied to European Neocomian species, but are more closely related to or identical with forms in the Umia beds of Cutch in India, for example *Trigonia ventricosa* and *T. holubi*. The fauna has been recognised in Tanganyika Territory, at Moçambique, and on the western side of Madagascar, while a few species are very like forms obtained in Bolivia, Chile, and Argentina. On the second point, Seward [3] has concluded that the flora of the Wood Beds is related to that of both the Upper Jurassic and the Wealden (Lower Cretaceous) of other countries, but more particularly to the latter; several species are identical with or closely allied to Indian forms occurring in the very uppermost Gondwana beds. The Wealden of England is hardly separable from the underlying Purbeck beds placed at the top of the Jurassic, while beneath the Uitenhage plant-bearing strata there comes quite an important mass of variegated marls and Enon conglomerate that has as yet yielded no fossils. It is hence quite probable that the

[1] F. L. Kitchin, *Geol. Mag.*, 1907, 289 and 480; *Ann. S.A. Mus.*, 1908, vii, pt. 2, in which full references are given to previous descriptions; J. V. L. Rennie, *S.A.J.S.*, 1934, xxxi, 227.

[2] L. F. Spath, *Ann. S.A. Mus.*, 1930, xxviii, 131.

[3] A. C. Seward, *Ann. S.A. Mus.*, 1903, iv, pt. 1.

earliest deposits of the Uitenhage Series date back into the *uppermost Jurassic.*

Fossils.—The following is a complete list of the invertebrate fossils from the Sundays River Beds :—

Anthozoa—
Isastræa richardsoni var. *antipodum* Tate.
Thamnastræa sp.

Annelida—
Serpula cf. *concava* J. Sow.
,, *pinchiniana* Tate.

Echinodermata—
Cidaris pustulifera Tate.

Polyzoa—
Berenicea antipodum Tate.

Lamellibranchiata—
Anthonya lineata Kitch.
Astarte (*Eriphyla*) *herzogi* (Goldf.).
Astarte (*Eriphyla*) *pinchiniana* Tate.
Astarte longlandsiana Tate.
Cardita nuculoides Tate.
Corbula ? rockiana Tate.
Cyprina borcherdsi Tate.
,, *rugulosa* Sharpe.
Cyrena ? baini Sharpe.
Cucullæa kraussi Tate.
Exogyra imbricata Krauss.
,, *jonesiana* Tate.
Gastrochæna dominicalis Sharpe.
Goniomya sp.
Grammatodon atherstonei Sharpe.
Grammatodon jonesi Tate.
Lima (*Mantellum*) *neglecta* Tate.
Lima (*Acesta*) *obliquissima* Tate.

Lamellibranchiata (*continued*)—
Lithodomus stowianus Tate.
Mactra ? dubia Kitch.
Meretrix uitenhagensis Kitch.
Modiola atherstonei Sharpe.
,, *baini* Sharpe.
,, *rubidgei* Tate.
Monodonta hausmanni Neum.
Mytilus jonesi Tate.
,, *uitenhagensis* Kitch.
Nucula uitenhagensis Kitch.
Ostrea sp.
Panope gurgitis (Brong.).
Pecten rubidgianus Tate.
,, (*Camptonectes*) *cottaldinus* d'Orb.
,, *Camptonectes projectus* Tate.
,, (*Chlamys*) cf. *subacutus* Lam.
,, (*Syncyclonema*) *orbicularis* J. Sow.
Perna atherstonei Sharpe.
Pholadomya dominicalis Sharpe.
Pinna atherstonei Sharpe.
,, *sharpei* Tate.
Placunopsis imbricata Tate.
,, *subjurensis* Tate.
,, *undulata* Tate.
Pleuromya baini Sharpe.
Psammobia atherstonei Sharpe.
Pteria baini Sharpe.
Ptychomya complicata Tate.
Seebachia bronni Krauss.
Solecurtus sp.
Tancredia schwarzi Kitch.
Thetironia oblonga Kitch.
,, *papyracea* Sharpe.

Lamellibranchiata (*continued*)—
Thracia sp.
Trapezium nivenianum Tate.
,, *? tatei* Kitch.
Trigonia conocardiiformis Krauss.
,, *herzogi* Goldf.
,, *holubi* Kitch.
,, *kraussi* Kitch.
,, *rogersi* Kitch.
,, *stowi* Kitch.
,, *tatei* Neum.
,, *vau* Sharpe.
,, *ventricosa* Krauss.
Unio uitenhagensis Kitch.

Gasteropoda—
Actæonina atherstonei Sharpe.
Alaria coronata Tate.
Limnæa remota Kitch.
Monodonta hausmanni Neum.
Natica atherstonei Sharpe.
,, *rogersi* Kitch.
,, *uitenhagensis* Kitch.
,, *? mirifica* Kitch.
Neritopsis ? turbinata Sharpe.
Patella caperata Tate.
Pleurotomaria patersonæ Rennie.
,, *wilmanæ* Rennie.
Turbo atherstonei Sharpe.

Gasteropoda (*continued*)—
Turbo minutulus Kitch.
,, *rogersi* Kitch.
Turritella rubidgiana Tate.

Cephalopoda—
Belemnites sp. 1 Kitch.
,, sp. 2 Kitch.
Belemnopsis africanus (Tate).
Bochianites africanus (Tate).
,, *glaber* Kitch.
Distoloceras spinosissimum (Haus.).
Eodesmoceras haughtoni Spath.
Eutrephoceras uitenhagense Spath.
Hoplitides subanceps (Tate).
Phylloceras rogersi Kitch.
Rogersites atherstonei (Sharpe).
,, *baini* (Sharpe).
,, *crassicostatus* Spath.
,, *kitchini* Spath.
,, *modderensis* Kitch.
,, *otoitoides* Spath.
,, *rogersi* (Kitch.).
,, *sphæroidalis* Spath.
,, *uitenhagensis*(Kitch.).
,, *wilmanæ* (Kitch.).

Crustacea—
Meyeria schwarzi Kitch.
Cyzicus (*Estheria*) *anomala* Jones.

B. The Gamtoos Valley Area [1]

Here the Cretaceous beds extend from Komdomo at the right-angled bend of the Gamtoos right down to the sea, while the river itself follows the middle of this belt, which is from 5 to 10 miles wide, and winds in a picturesque valley floored by fertile alluvial plains overlooked in places by cliffs of red conglomerate (Fig. 55). On the south-west the strata rest unconformably on folded Bokkeveld slates and dip north-eastwards towards a curving

[1] J. J. Frankel, *T.G.S.S.A.*, 1937, xxxix, 263; S. H. Haughton, H. F. Frommurze, and D. J. L. Visser, *Union S.A.G.S.*, Expln. Sheet 151, 1937.

fault-plane, where the Cretaceous has been thrown down against the pre-Cape beds. Coarse conglomerates of the Enon type with occasional breccias or finer-grained intercalations predominate, as at Patentie ; but towards the mouth of the Gamtoos the beds as a whole become finer, passing into false-bedded, light-coloured sandstones with reddish marls and grey sandy clays, that build prominent cliffs on the east bank. From two to four miles up the valley of the Loerie River grey sandy clays with lenticular layers of lignite (probably mostly carbonised stems), marcasite, and small lumps of fossil resin have been unsuccessfully prospected for coal. Plants occur in these clays, the majority being of species known from the Wood Beds of the Sundays River area (see list on p. 379) ; fossil wood appears to be absent, nor have marine mollusca been found.

C. The Oudtshoorn-Uniondale-Baviaans Kloof Area [1]

Baviaans Kloof is remarkable because along it through a distance of nearly 50 miles there are strung out a number of elongated basins of Enon Conglomerate dipping northwards and ending against the Ladismith-Baviaans Kloof Fault—against towering fault-scarps in stretches—along which the Table Mountain Sandstone has in places been shattered on a huge scale. The varying southerly throw of that fracture, coupled with erosion, has developed " fault-basins " in which deposits of " Red Enon " and sometimes of " White Enon," like those farther west, have been preserved.

The Olifants River traverses three basins. The easternmost, 16 miles long, extends from Toverwater Poort westwards ; the second runs from Uniondale Road past Vlakteplaats for 24 miles with a width of 4 miles. A sharp up-ridging of the " floor " about Stompdrif has cut it off from the third or " Oudtshoorn " trough, 60 miles long by 10 to 24 miles wide, that ends against the barrier range of the Roodeberg beyond Calitzdorp. The Cretaceous rests with strong unconformity upon the highly cleaved Bokkeveld slates as a rule and shows a general northerly dip of over 10 degrees that rises in the east to as high as 45 degrees in places (Fig. 58). On the north it has been dropped, with local crushing, against

[1] E. H. L. Schwarz, *Ann. Rep. G.C. for* 1903, 73 ; J. de Villiers, *T.G.S.S.A.*, 1939, xli, 37 ; 1942, xliv, 151 ; J. W. du Preez, *Ann. Univ. Stellenbosch*, 1944, xxii, Sect. A, 209.

the straight fault or group of faults running along the base of the Swartebergen past Le Roux and Calitzdorp, the course of which is obscured by scree, gravel, or soil. The total thickness must exceed 10,000 feet at Oudtshoorn.

(*a*) As in the Uitenhage area, the brilliantly red Enon Conglomerate is prominently developed at the base and is usually of great thickness. It is crammed with well-rounded pebbles and boulders of Table Mountain quartzite and more angular Bokkeveld slate and vein quartz, set in a scanty hæmatitic matrix. Crushing of the pebbles is not unusual. Irregular bands and lenses of grit or sandstone are common, while cross-bedding is

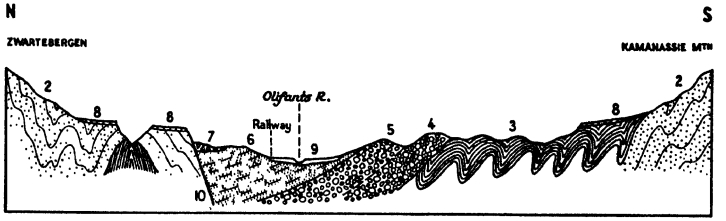


FIG. 58.—Diagrammatic section near Vlakte Plaats, Uniondale district, length about 8 miles. 1, Cango Beds; 2, Table Mountain Sandstone; 3, Bokkeveld Slates; 4, "Red" Enon; 5, "White" Enon; 6, Cretaceous Sandstones and Mudstones; 7, Scree deposits; 8, High-level Gravels on Tertiary Terrace; 9, Alluvium; 10, Ladismith-Baviaans Kloof Fault.

marked. The upper part carries smaller pebbles, while secondary gypsum becomes conspicuous.

In the eastern region the Conglomerate is differentiated into a deep-red variety in the lower half and a strongly contrasting white one above (Fig. 58). Being underlain for long stretches by Bokkeveld beds, inclusions of slate are abundant therein, particularly near the base, to be replaced by quartzite higher up—right to the summit of the formation.

(*b*) The Enon is abruptly succeeded by a group of red, blue, and greenish mudstones and clays intercalated with soft yellowish or buff sandstones containing gritty bands and some small pebble conglomerates, thus paralleling the Variegated Marls of the Uitenhage area. They are at least 500 feet thick near Oudtshoorn and owing to their softness have been followed by the Olifants River from Van Wyks Kraal Station onwards. Succeeding them comes a group of unknown thickness characterised by buff or

greenish current-bedded sandstones with washes of pebbles and drab, sandy mudstones and clays with some limestones; they have been opened up in the town of Oudtshoorn and are exposed at Langverwacht to the west. Their position, colouring, included fragments of fossil wood and occasional pockets of lignite (in the east) make them the representative of the Wood Beds. A fragment of *Cladophlebis* and a few dinosaurian teeth have been obtained from near Oudtshoorn. These two higher groups of sediments are well developed on the northern side of the Vlakteplaats basin and are just represented in that of Toverwater Poort.

(*c*) At the top of the succession, next the boundary fault, lies a group of "red beds" showing no sorting and marked by large boulders of quartzite and by occasional red sandstone lenses. These conglomerates weather out into some striking hills, peculiarly pitted and hollowed out in places, as near Le Roux or Snyberg stations.

(*d*) All these Uitenhage beds are essentially *torrential deposits accumulated under an arid climate with strong oxidation.* It is significant that throughout this region inclusions derived from the near-by Cango beds are wanting, proving—as in the Worcester-Ashton area—that the pre-Cape formations were not exposed at that period.

D. The Knysna District[1]

Passing westwards along the coast three basin-like areas of conglomerates, quartzites, sandstones, and clays are found occupying deep valleys cut in the Cape formations, two of which owe their position in part at least to faulting. As elsewhere, the pebbles and boulders in the conglomerates are mostly of the hard Table Mountain sandstone.

The first of these is at Plettenberg Bay along the lower part of the Bitou River, where there is a great mass of conglomerate with angular instead of rounded inclusions and loose sandy beds with pockets of lignite. A separate area lies to the south bounded on its northern margin by a fault-face of Table Mountain sandstone along which the Pisang River flows; it extends east and south to the shore and juts out in the narrow peninsula of Robberg. The strata are less conglomeratic and more sandy and clayey than in the basin to the north, but some of the beds have been rendered quartzitic through deposition of

[1] *Ann. Rep. G.C. for* 1899, 59.

silica between the original sand grains; indeed, in this peninsula such intensely hard quartzites and conglomerates are sometimes difficult to distinguish from the underlying Table Mountain sandstone.

Near Robberg casts of *Trigonia conocardiiformis*, a characteristic form of the Sundays River beds, occur on some of the slabs of quartzite, the only marine fossils as yet found in strata of the Enon type. The evidence from these two basins indicates that the water in which the Cretaceous strata were laid down deepened rapidly to the south and became salt in that direction, a similar condition obtaining to the west about the town of Knysna.

On the north of the latter—particularly well seen in the Phantom Pass—appear massive beds of conglomerates and gravels to a thickness of at least 600 feet, in which boulders of various sizes are tumbled together in a manner recalling an ancient landslide. Just to the south-east of the town along the narrow gauge railway to the Knysna forests conglomerates are overlain by red and green sands and clays, which dip northwards towards a boundary fault, the prolongation of which westwards across the Knysna harbour would explain the presence at Brenton, on that side, of marine beds lying horizontally at lagoon level. The lowest strata are shelly conglomerates with *Ostrea* and *Trigonia kitchini* Schwarz; above come blue-grey clays with calcareous nodules that have yielded *Nautilus*, *Belemnites*, *Acanthodiscus*, *Trigonia holubi*?, *Ptychomya complicata* Tate, *Meretrix uitenhagensis* Kitchin, *Perna theseni* Schwarz, and *P. brentonensis* Schwarz, several of which are forms from the Sundays River beds.[1] Trigonia-beds are exposed just inside the Heads.

E. The Mossel Bay Area [2]

From the Great Brak River a broad belt of Uitenhage beds extends westwards across the Gouritz River for a distance of fifty miles. On the south they rest on an uneven surface of Table Mountain Sandstone and Bokkeveld beds, their base descending well below sea-level; on the north they abut against ridges of Cape and pre-Cape rocks through a fault—perhaps an overthrust. At Great Brak River Station red and white clays and sands contain bands full of angular lumps of granite-gneiss, and dip northwards towards that formation, the fault-scarp

[1] *Ann. Rep. G.C. for* 1905, 74; *for* 1908, 130. E. H. L. Schwarz, *Rec. Albany Mus.*, 1915, iii, 120.

[2] *Union S.A.G.S.*, 1937, Sheet 201 and Expln.

running eastwards out to sea in a picturesque headland. The Cretaceous laps around the western end of the George granite, in which direction conglomerates are found to have a considerable development. Throughout the whole thickness, which must be considerable, pebble-beds occur among the sandstones, variegated mudstones, and shales.

Three miles east of Herbertsdale some shales, opened up in prospecting pits dug because of the presence of fragments of lignite, furnished remains of the following plant genera :— *Cladophlebis*, *Osmundites*, *Tæniopteris*, and *Taxites*, all but the last fo which occur in the Wood Beds at Dunbrodie (see table on p. 379).

At Cape St. Blaize, an instructive patch of these beds rests horizontally and with conspicuous discordance upon the edges of the Table Mountain sandstones. The surface on which they repose is uneven, with a few inches of a basal breccia made up of fragments from the underlying formation. These beds consist of fairly hard whitish sandstones and have been opened out in quarries as a building stone ; along the cliffs to the west the rocks are softer. Certain bands contain bits of wood, fragments of plants or casts of stems, some of a cycadean type.

F. The Riversdale-Heidelberg Area

This, which is 30 miles long and 8 miles at its broadest, occupies a position beneath the Langebergen precisely similar to the foregoing. Indeed, the sediments filling the several basins from Mossel Bay to Worcester were manifestly deposited in a single trough, having been separated by differential sagging and erosion. The strata in this basin again dip northwards, so that they must be thousands of feet in thickness, but curve round at both ends, the northern boundary being probably a fault-line. Conglomerates play a less important part here than in the other basins but, while developed principally at the base, are not restricted to such a horizon. Nevertheless, as in the other areas, the higher beds are mostly soft, consisting of whitish sandstones with occasional pebbles and red, pink, grey, blue, or green clay-shales and hard white argillaceous beds, thus paralleling the Variegated Marls and Wood Beds of the Uitenhage basin.

At Heidelberg some pale siliceous shales are crowded with the thin shells of an entomostracan, *Cyzicus* (*Estheria*) *anomala* Jones, a form which has been found at many other places in the district but appears to be confined to this basin. With it is *Cypris* probably, some fish-scales

and some badly preserved freshwater shells closely resembling *Unio uitenhagensis* from the Wood Beds near Blue Cliff.

Strikingly on the farm Spiegel River to the north-east of the town of Heidelberg the Cretaceous is pierced by an intrusive plug of alnöite (melilite basalt),[1] while on Kruis River six miles to the west Harger has recorded a kimberlitic pipe carrying big xenoliths of Cretaceous beds, and dykes of ultrabasic rock on this and the adjoining farm Doornhoek (see p. 424).

G. The Swellendam Area

This patch is about 12 miles long and 5 miles wide, extending from the town of Swellendam to beyond the Buffeljagts River. The rock near the western end seems to be chiefly composed of conglomerates containing pebbles derived mainly from the Bokkeveld beds. A bore-hole at the railway station in Swellendam failed to reach the base of the formation at 350 feet; it passed through a boulder of micaceous slate 7 feet in diameter not far from the bottom. Railway cuttings east of the town show sandy clays interbedded with the conglomerates.

H. The Ashton-Worcester Area

The Enon conglomerate in the region between Ashton and Robertson, 15 miles long by 6 miles wide, rests upon Witteberg beds and is faulted against them or the Malmesbury beds bounding them to the north. Rastall [2]—corroborated by Söhnge—has discovered not only here but in the outliers at Nuy and at Worcester that inclusions of Malmesbury and probably of Table Mountain sandstone are absent from the conglomerate and that the rounded and sub-angular boulders and pebbles embedded in a scanty, reddish, sandy matrix consist of hard, dark Ecca grits and sandstones, Dwyka conglomerate, and Witteberg quartzites. This goes to show that, when the Enon was formed, neither the Malmesbury, nor apparently the Table Mountain sandstone, was exposed in this area, though those formations—on the opposite side of the great fault—now tower above the Cretaceous strata at their base. The dislocation has near Robertson the enormous throw of probably not less than 12,000 feet.

The red to green conglomeratic strata rest on Ecca beds at Nuy Station and at, and again 3 miles west of, the town of Worcester, the latter forming the most westerly outcrop in the Cape.

[1] *Ann. Rep. G.C. for* 1897, 51; *for* 1901, 7. M. S. Taljaard, *T.G.S.S.A.*, 1936, xxxix, 281.

[2] *Q.J.G.S.*, 1911, lxvii, 701; P. G. Söhnge, *T.G.S.S.A.*, 1935, xxxvii, 253.

(ii) The Neocomian of Pondoland

(1) *The Umgazana Beds.*[1]—Though merely a tiny patch at the entrance of the Umgazana River a little to the south of Port St Johns, this occurrence has furnished some useful information about the geological history of South Africa during the Cretaceous.

Resting on tilted Molteno beds, this formation dips at an angle of 20° east-north-east and consists of dark greenish conglomerates crammed with boulders and pebbles principally of dolerite, also lumps of Karroo sandstone and lydianite and significantly of the Stormberg amygdaloidal basalt and agates therefrom. Some bands of fine-grained conglomerate and greenish grit are also present and the whole clearly constitutes a beach accumulation. A lenticle of limestone has furnished some marine fossils, including the genera *Baculites, Pseudomelania, Trigonia,* and particularly *Thetironia,* common in the Lower Cretaceous, while plant fragments have proved the presence of the genera *Onychiopsis, Cladophlebis, Nilssonia, Dictyozamites,* and *Otozamites,* the last found recently in the Lebombo region. The flora indicates an age not younger than the Wealden and the formation consequently appears to be the precise equivalent of the Uitenhage Series.

(2) *The Embotyi Beds.*[2]—Discovered in 1901, these cover a triangular area south of the Egosa Forest, a short distance to the north of Port St Johns. The formation rests upon much tilted Beaufort beds and dolerite, and dips north-eastwards at angles that increase in that direction but flatten out near the great boundary fault by which it has been dropped against the Table Mountain sandstone of the plateau to the north. The face of the Egosa Fault is disclosed by a long cliff some 300 feet high known as Waterfall Bluff.

Like those at Umgazana, 25 miles away, the beds are mainly conglomerates and breccias crowded with fragments of Karroo dolerite, sandstone, lydianite, and shale, in great part angular. Huge dolerite inclusions are present on various horizons, the biggest seen being 18 feet long.

Other types of strata are absent except a few sandy layers, some of which contain fragments of carbonised wood. Although search has

[1] *Union S.A.G.S. Rep. for* 1912, 153; Expln. Sheet No. 28 (Cape).
[2] *Ann. R.G.C. for* 1901, 23; *Union S.A.G.S.*, 1920, Expln. Cape Sheet 28.

not yet brought to light any fossils, it is practically certain from the numerous points of resemblance with the Umgazana Beds that the Embotyi formation is equivalent to the latter and hence of Lower Cretaceous age, and was laid down most likely a little distance back from the actual coast-line. It is worth noting that the Table Mountain Series of the immediate neighbourhood did not contribute to this formation, showing that this sandstone was at that time still buried beneath Karroo beds. While these two areas of Lower Cretaceous rocks experienced considerable disturbance, the Upper Cretaceous (Umzamba) beds not far to the north rest almost horizontally on the Table Mountain sandstone and carry pebbles of the latter. The Umzamba beds are presumably *younger* than the important system of fracturing that has affected the Continental Margin of this region.

(iii) The Lower Cretaceous of the Lower Zambezi Area

According to the geologists of the Inyaminga Petroleum Company [1] the strata that constitute the lower part of the Lupata Series (p. 318) are traceable southwards for fully 100 miles with a width of up to 10 miles, consisting of conglomerates, coarse sandstones, and sandy shales resting unconformably on Karroo lavas and dipping gently eastwards beneath the Urema flats (Fig. 62). It is believed, furthermore, that they were struck beneath the Senonian in the deep borings at Inyaminga (p. 407). On the Muda River trunks of trees occur in their presumed extension. Comparable non-marine red, and in places conglomeratic, sediments are known from the Ruya River west of Tete, and have a wide development in Nyasaland, where they have yielded dinosaurian remains.

They may ultimately prove of Lower Cretaceous age, though the basal part may even be older.

II. The Aptian Stage

Fossils belonging to this division of the Cretaceous were first recorded by Kilian [2] in 1902 from Lourenço Marques in Portuguese East Africa, and described in detail later by Krenkel.[3] In Zululand the Pongola River after emerging from the Lebombo Range exposes at least 800 feet of fossiliferous beds dipping faintly seawards, largely buff sandstones and sandy shales with occasional

[1] From notes supplied by Dr Pires de Carvalho.

[2] W. Kilian, *Bull. Geol. Soc., France*, 1902, ii, 358; *Comp. Rend.*, 1902, cxxxv, 68; *Centr. Min. Stutt.*, 1902, 456.

[3] E. Krenkel, *Neu. Jahrb.*, 1910, i, 142.

conglomerates, grits, limestones, and logs of wood. Provisionally they are thought to range from Lower Aptian (possibly Neocomian) to Upper Albian or even Cenomanian.[1] Of the lamellibranchs those from the lowest stage—here and on the Umsinene as well—recall Uitenhage forms. There is a scarcity of gasteropods. The similar succession on the Umsinene is referred to below. Near Catuane on the Usutu River, just north of the Zululand boundary, Aptian fossils have been found, among which is *Ancyloceras fallauxi*, while Spath has determined three forms belonging to this fauna from light-yellowish calcareous sandstone at Powell's Camp on the Tembe River.

In view of the poor exposures of the softer strata, it will be of use to record their nature as indicated from two boreholes. One of them is 210 feet deep sunk on the Tembe River in lat. 26° 6′, long. 32° 29′ and proved, in addition to pale hard, shelly limestones and yellowish calcareous sandstones, some sandy beds rich in dark-green glauconite; one band was charged with volcanic detritus, including pebbles of rhyolite. The second borehole was 187 feet deep, located on the Changalane River, a branch of the Tembe, lat. 26° 18′, long. 32° 20′, less than a mile to the east of the rhyolitic lavas of the Lebombo. It pierced very similar materials, varying from medium-grained beds with grains of weathered feldspar and granules of glauconite to buff and brown claystones largely and perhaps wholly made up of sediment derived from the volcanic ridges to the west. Pieces of lignite were passed through and there were also worm-casts, a few shells, and some nodules of pyrite associated with barite.[2] The determination of the ammonite *Cheloniceras gottschei* (Kilian) proved that the Aptian ocean actually lapped the base of the Lebombo. Near Bohane, according to R. B. Young, the railway to Goba cuts through soft chocolate-brown sandstones containing layers of well-rounded pebbles of rhyolite, agate, etc., dipping at a very gentle angle eastwards, probably the base of this formation.

Fossils.—The following forms have been recorded from the region extending southwards from Delagoa Bay :—

Lamellibranchs—
Anomia lævigata Sow.
Pinna cf. *robinaldina* d'Orb.

Cephalopods—
**Aconeceras nisoides* Saras.
Ancyloceras ackermanni Kil.

(Those from Powell's Creek are marked with an asterisk.)

[1] J. V. L. Rennie and S. H. Haughton, *Ann. S.A. Mus.*, 1936, xxxi, 277.

[2] I am indebted to Major J. D. Berrington for cores, sections, and fossils from these and other boreholes.

Cephalopods (*continued*)—
Ancyloceras fallauxi Uhl. var. *mozambiquense* Krenk.
Cheloniceras albrecht-austriæ (Hoh.).
Cephalopods (*continued*)—
**Cheloniceras delagoense* (Krenk.).
* ,, *gottschei* (Kil.).
,, *royerianum* (d'Orb).

(Those from Powell's Creek are marked with an asterisk.)

The relationships of this fauna have been discussed by Krenkel,[1] while Spath [2] has remarked that the horizon represented is probably the Upper Aptian.

III. The Albian-Cenomanian Stages

A highly fossiliferous succession ranging from Aptian to Senonian—and embracing the above stages—is exposed along the Umsinene River [3] that flows into False Bay in Zululand, and also its tributary the Manuan (Munyuana) Creek and its branches.[4] Of the large collections made therefrom the forms described by Etheridge junior, Crick, Newton, Spath, and van Hoepen have come mainly from the second area. The lowest beds, on the Umsinene, include fossil wood and conglomerates with large *Trigoniæ* and may be as old as Upper Neocomian. Sandstones, marls, and sandy limestones—Albian and higher—follow, but on the middle Manuan Creek a small outlier of Albian rests directly on rhyolite, according to Anderson, confirmed by Wybergh, a proof of the unevenness of the floor.

About the junction of the Manuan with the Umsinene and down the latter appear calcareous sandy shales and sandstones crowded with *Acanthoceras*, indicating the Cenomanian. East of the hillock known as the Skoenberg these pass up into beds characterised by *Peroniceras* and representing the Senonian, these being present as well on the southern branch of the Manuan (see p. 406). Van Hoepen has claimed the presence here of the Turonian stage and of an unbroken sequence of Cretaceous, a relationship that would be unique for southern Africa. Some support is got from the species of *Inoceramus* [5]; but, until the cephalopods have been fully determined, the existence of the whole or a part of the Turonian can be questioned and a *disconformity* presumed, as suggested by other evidence.

[1] E. Krenkel, *Geol. Rundsch., Leipzig*, 1911, ii, 330.
[2] *Ann. S.A. Mus.*, 1921, xii, pt. 7, 311.
[3] E. C. N. van Hoepen, *S.A.J.S.*, 1926, xxiii, 216; *XV Inter. Geol. Congr.*, 1929, Guide book, Exc. C. 18, p. 10.
[4] W. Anderson. *Third Rep. G.S. Natal*, 1907, 57.
[5] R. Heinz, *XV Geol. Inter. Congr.*, 1930, ii, 681.

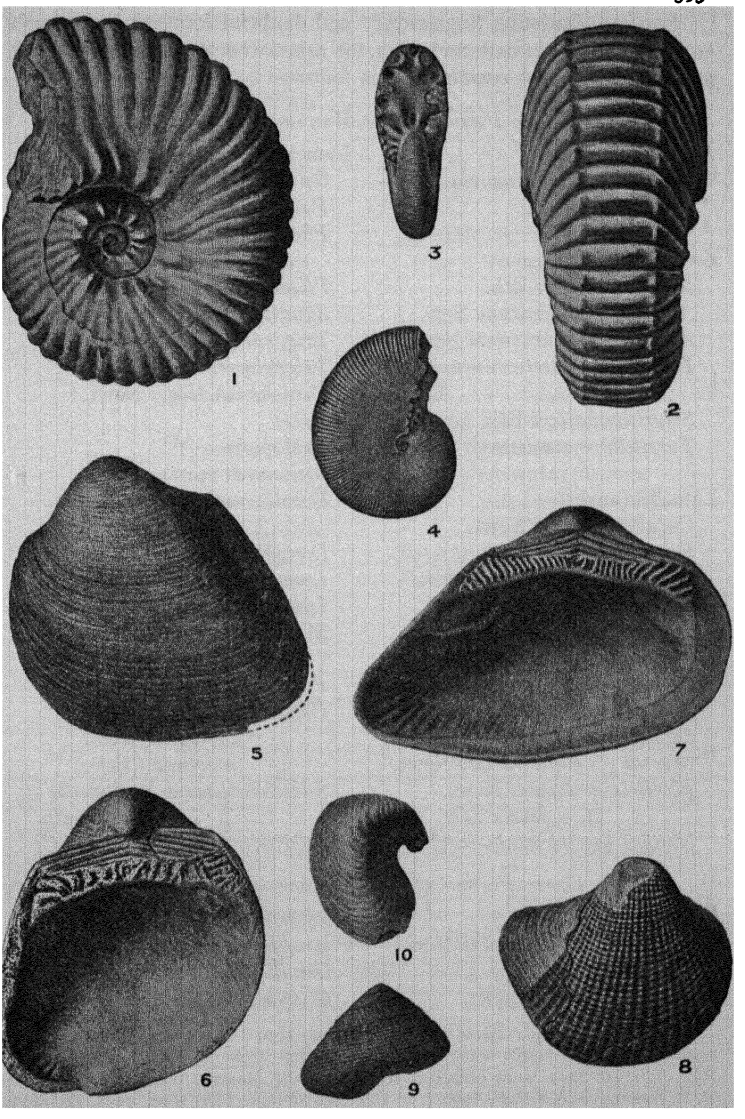


FIG. 59.—Albian and Cenomanian Fossils from Zululand. 1, 2, *Acanthoceras choffati*; 3, 4, *Phylloceras velledæ*; 5, 6, *Cucullæa woodsi*; 7, *Trigonarca ligeriensis*; 8, *Pholadomya vignesi*; 9, *Architectonica africana*; 10, *Exogyra conica*.

Fossils.—Omitting fragmentary and doubtful forms and also such as must have been collected from the associated Senonian strata, the principal molluscan remains are as follows [1] :—

(a) *Upper Portion of the Manuan Creek—Albian.*

Annelids—
Serpula pinchiniana var. *umsinensis* Eth.

Gasteropods—
Alaria (?) *bailyi* Eth.
Avellana cf. *incrassata* Sow.
Architectonica kossmati Newt.
Pseudomaura terrazuluensis Eth.
Solarium hedleyi Eth.
Turritella manuanensis Newt.

Lamellibranchs—
Cucullæa woodsi Newt.
Exogyra conica Sow.
,, cf. *flabellata* Goldf.
Glycymeris griesbachi Newt.
Inoceramus choffati Woods.
,, *volviumbonatus* Eth.
Lima cf. *gaultina* Woods.
Lithophaga manuanensis Newt.
Mactra (?) *rupert-jonesi* Newt.
Meretrix andersoni Newt.
,, cf. *caperata* Sow.
Neithea quadricostata Sow.

Lamellibranchs (*continued*)—
Ostrea zululandiæ Newt.
Parapholas tatei Eth.
Pholadomya luynesi Lartet.
,, *vignesi* Lartet.
Plicatula andersoni Newt.
Syncyclonema orbicularis Sow.
Trigonarca ligeriensis d'Orb.
Trigonia cricki Newt.
Veniella etheridgei Newt.

Cephalopods—
Anisoceras sp.
Dipoloceras cristatum Deluc.
,, *quadratum* Spath.
Douvilleiceras sp.
Lyelliceras nodosum Eth.
Lytoceras crenulatum Crick.
Manuaniceras manuanense (Spath.)
Phylloceras velledæ Michelin.
Puzosia cf. *bhima* Stol.
,, *compacta* Crick.
,, *concinna* Crick.
Subschlœnbachia prerostrata Spath.
Turrilites cf. *gresslyi* P. & C.

(b) *Lower Portion of Manuan Creek—Cenomanian.*

Gasteropods—
Architectonica africanus New.
Perissoptera sp.
Scala zululandiæ Newt.

Lamellibranchs—
Exogyra conica Sow.
Gervillia sublanceolata d'Orb.
Glycymeris griesbachi Newt.

[1] R. Etheridge, jr., *Third Rep. G.S. Natal*, 1907 ; G. C. Crick, *ibid.* Crick assumed that the fossils which he described came from the north end of False Bay, whereas they were obtained from near the Manuan-Umsinene junction. R. B. Newton, *T.R.S.S.A.*, 1909, i, 1 ; L. F. Spath, *Ann. S.A. Mus.*, 1921, xii, 217; E. C. N. van Hoepen, *Palæont. Nav. Nas. Mus. Bloemfontein*, 1929, i, 1 ; 1931, i, 2 ; 1941, i, 3 ; 1942, i, 4 ; 1944, i, 5, has described a host of Albian ammonite genera and species belonging to the families Brancoceratidæ, Dipoloceratidæ, Pervinquieridæ, etc.—a task still in progress.

Lamellibranchs (*continued*)—
Plicatula rogersi Newt.
Trigonarca ligeriensis d'Orb.
Trigonia blanckenhorni Newt.
,, cf. *scabra* Lam.

Cephalopods—
Acanthoceras cornigerum Crick.
,, *choffati* Kossm.
,, *crassiornatum* Crick.
,, *expansum* Crick.
,, *flexuosum* Crick.
,, *hippocastanum* Sow.
,, *laticostatum* Crick.
,, *latum* Crick.
,, *munitum* Crick.
,, *newboldi* Kossm.
,, *nitidum* Crick.
,, *paucinodatum* Crick.
,, *quadratum* Crick.
,, *robustum* Crick.

Cephalopods (*continued*)—
Desmoceras inane Stol.
Forbesiceras largiliertianum d'Orb.
,, *nodosum* Crick.
,, *sculptum* Crick.
Gaudryceras odiense Kossm.
,, *sacya* Forbes.
Nautilus imbricatus Crick.
,, *occlusus* Crick.
,, *ovoideus* Crick.
,, *striaticostatus* Crick.
Phylloceras cf. *ellipticum* Kossm.
,, *velledæ* Stol.
Puzosia pinguis Crick.
,, *planatula* Crick.
,, *stoliczkai* Kossm.
,, *subcompressa* Crick.
,, *subtilis* Crick.
Tetragonites timotheanus Stol.
Turrilites acutus Passy.
,, *costatus* Lamk.
,, *nodiferus* Crick.
,, *scheuchzerianus* Bosc.

The succession at Catuane in Portuguese East Africa includes, according to Haughton, Albian forms such as *Avellana incrassata* (J. Sow.), while Spath [1] has described the following species of cephalopods :—*Anisoceras* aff. *armatum* (J. Sow.), *Desmoceras latidorsatum* (Mich.), *Elobiceras newtoni* Spath, *Hysteroceras choffati* Spath, *Inflaticeras africanum* Spath, *I. haughtoni* Spath, *I. recticostatum* Spath, *Labeceras plasticum* Spath, *Myloceras amaltheia*, *M. cornucopia* Spath, *M. serotinum* Spath, and *Phylloceras velledæ* (Mich.).

In addition the Umsinene has yielded the coral *Carophyllia skœnbergensis* Mont.-Gall., and the echinoderms *Hemiaster stefanini* Lang, *Holaster marinellii* Lang, *H. van hoepeni* Lang, and *Periaster insolitus* Fourt.[2]

Relationships

The relationships of these several faunas are in the case of the gasteropods and lamellibranchs with those of the Uitenhage and

[1] *Ann. Transv. Mus.*, 1925, xi, 179.
[2] E. Montanaro-Gallitelli and Z. Lang, *Palæont. Italica*, 1937, xxxvii, 193.

the Utatur of India, while the cephalopods display for the most part affinities with those of Europe, India, and Madagascar, and in a couple of instances with forms from Angola ; but the faunas are not at all closely related to the latter, which possess marked Mediterranean affinities.

The Turonian Stage is not positively known in South Africa though represented in Angola and Madagascar. During that period upheaval with some denudation of previously formed Cretaceous appears to have been general, coincident seemingly with the faulting that took place in the coastal regions of the Cape.

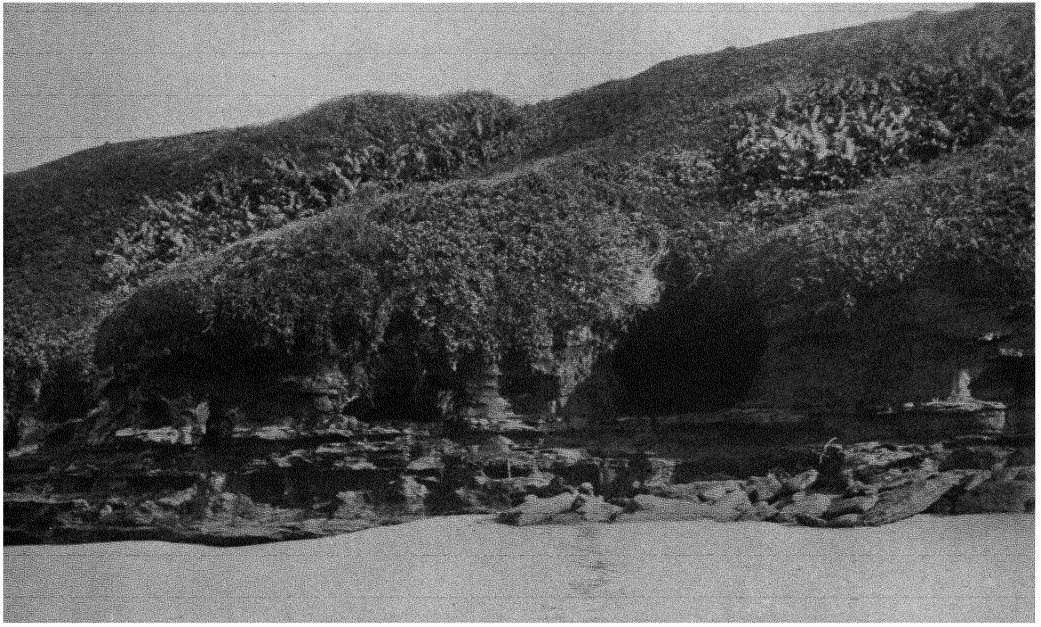
IV. The Senonian Stage

Beds belonging to this division fringe the coast from the Umtata River northwards, underlie parts of the lowlands of Zululand and may be widely distributed in Portuguese East Africa. There was an important world-wide marine trangression at this date, so that the Senonian came to rest on various divisions of the Cretaceous or upon much older formations ; but emergence of the land shortly afterwards stripped the beds from much of the territory that had just previously been submerged.

A. The Umzamba Beds of Pondoland.—These rocks and their fossils were made known so far back as 1855 by Baily and Garden,[1] and subsequently in more detail by Griesbach. A further account was given by Rogers and Schwarz [2] under the name of the Umtamvuna Beds, later changed to Umzamba, since the strata were not actually exposed at the mouth of the Umtamvuna River. Fringing the shore the rocks generally show up only between tide-marks, making an interrupted ledge usually awash and overgrown with seaweed, while the white sandy beach and the scrub-covered sand-dunes at the back thereof conceal the geology away from the shore. Nearly continuous ledges, however, are to be seen from just south of the Umtamvuna almost to the Umtentu River, and again for several miles between the latter and the Umsikaba. Fine cliffs of these rocks rising to a height

[1] W. H. Baily, *Q.J.G.S.*, 1855, xi, 454 ; C. L. Griesbach, *ibid.*, 1871, xxvii, 53.

[2] *Ann. Rep. G.C. for* 1901, 38 ; *Union S.A.G.S. Rep. for* 1912, 175 ; Cape Sheet 28 and Expln., 1920 ; W. J. Plows, *Ann. Durban Mus.*, 1921, iii, 58.



Upper Cretaceous Beds on the coast about three-quarters of a mile north-east of the Umzamba River mouth, Pondoland.

[*Face page* 398

of 50 feet run from the Umzamba mouth for about half a mile to the north and hold a number of small caves, thus affording good sections for fossil collecting (Plate XXXVII).

The limited exposures suggest that these beds are resting directly on the adjoining Table Mountain Sandstone and are not faulted down against the latter, as believed by Griesbach. Indeed, the basal bed—exposed at tide-level—is full of pebbles of that sandstone in addition to inclusions of lydianite, while several layers are rich in sandstone debris.

Lithology.—Hard shelly limestones alternate with sandy calcareous clays, though not constant, so that sections far apart are no longer closely comparable. They are crowded with shells, both complete and in fragments, which are often rolled and worn, along with quartz sand and occasional small pebbles. The other strata are blue in colour and very tough when in the fresh condition but, where exposed, have lost their calcareous cement and have become altered to soft brownish rocks out of which the fossils can readily be dug. The basal stratum, as mentioned, contains many water-worn pebbles along with logs of wood, blackened and partly silicified and often bored into by *Teredo*, sometimes having the shells of that organism still embedded in the perforations. Sharks' teeth occur and chelonian and reptilian bones as well.

The facies is that of a shallow-water deposit to commence with; the finer-grained sediments higher up point to a progressive deepening of the sea. The lowest bed is characterised by many ammonites and lamellibranchs, the soft band just above by delicate echinoderms; higher up numerous cross-sections appear of a huge *Inoceramus* from 2 to 3 feet across with fibrous shell, while all the limestones are crowded with *Trigonia*. One layer is rich in gasteropods, while the softer strata include numerous foraminifera and ostracods.

Fossils.—Of the commonest may be mentioned the ammonite genera *Hauericeras*, *Pseudoschlœnbachia*, *Mortoniceras*, *Gaudryceras*, *Phylloceras*, *Hamites*, and *Baculites*, the lamellibranchs *Trigonia*, *Astarte*, *Trigonocallista*, *Pecten*, *Inoceramus*, and *Protocardia*, the gasteropods *Pseudomelania*, *Turritella*, and *Pyropsis*, and the sea-urchins *Hemiaster* and *Cardiaster* (Figs. 60 and 61).

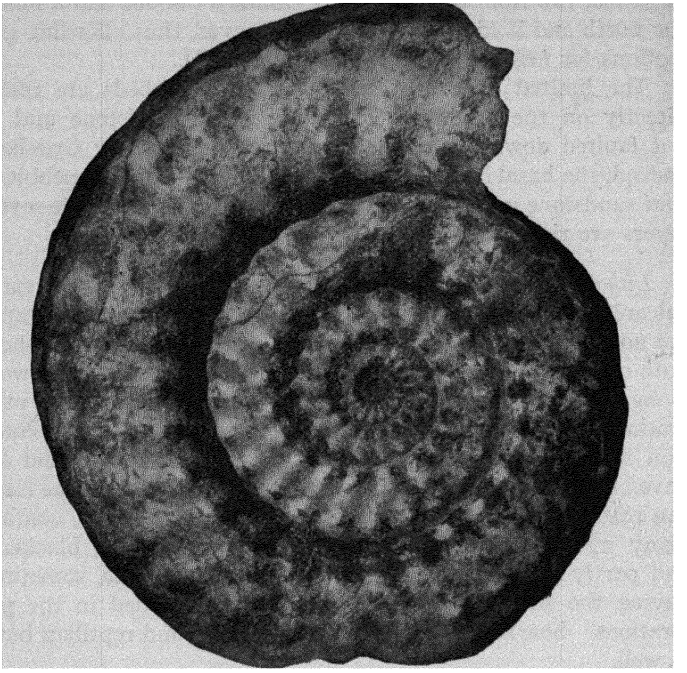


FIG. 60.—Ammonite, *Mortoniceras soutoni* (Baily) (reduced) from the Senonian beds of Pondoland.

The following lengthy list includes most of the 160 forms described,[1] those marked with an asterisk occurring at Umkwelane Hill.

Echinoids—
Cidaris cf. *hirudo* Sorig.
Cardiaster africanus Woods.
Cassidulus umbonatus Woods.
Hemiaster forbesi Baily.
Pseudodiadema griesbachi Woods.

Lamellibranchs—
Alectryonia cf. *arcotensis* (Stoliczka).
Astarte griesbachi Woods.
Barbatia meridiana Woods.
**Cardium denticulatum* Baily.
,, *griesbachi* Woods.

[1] Descriptions will be found under Baily and Griesbach cited earlier; the foraminifera and ostracoda have been identified by Chapman, *Ann. S.A. Mus.*, 1904, iv, pt. 5, and *T.G.S.S.A.*, 1923, xxvi, 1; the polyzoa by Lang and the mollusca generally by Woods, *Ann. S.A. Mus.*, 1906, iv, pt. 7, and Rennie, *Ann. S.A. Mus.*, 1930, xxviii, 159; the cephalopods by Spath, *Ann. Durban Mus.*, 1921, iii, pt. 2, and *T.R.S.S.A.*, 1922, x, 113, and van Hoepen, *Ann. Transv. Mus.*, 1920, vii, pt. 2, 142; 1921, viii, 1.

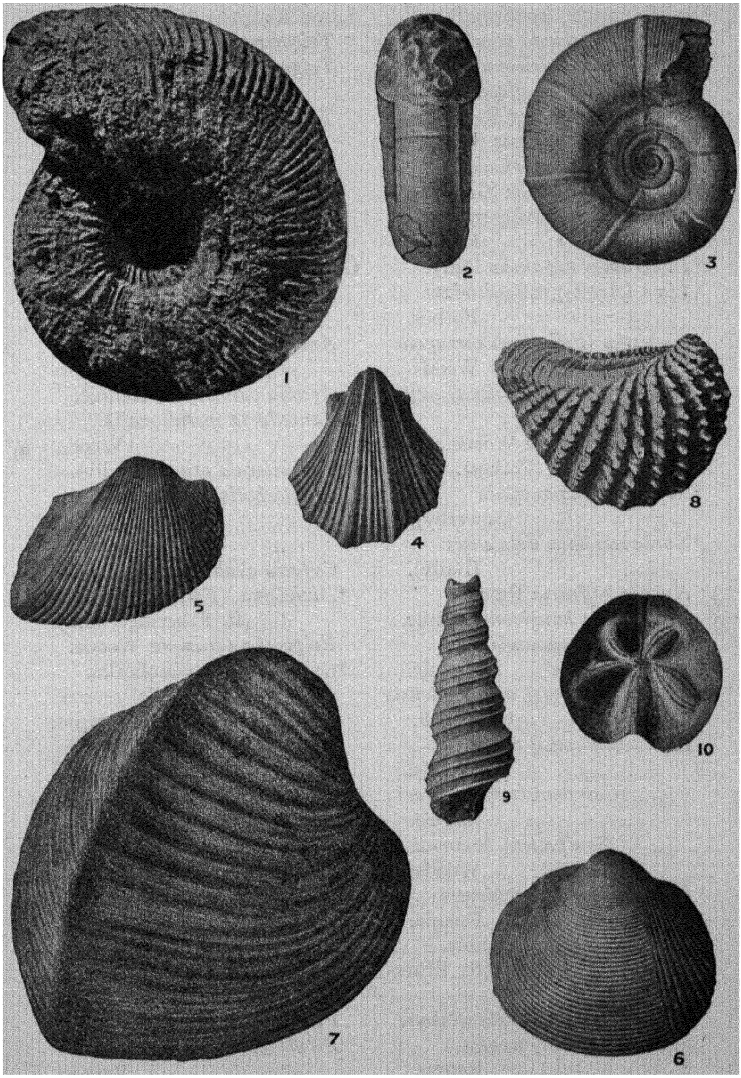


FIG. 61.—Senonian Fossils from Pondoland and Zululand. 1, *Kossmaticeras bhavani*; 2, 3, *Gaudryceras pulchrum*; 4, *Neithea quinquecostata*; 5, *Nordenskjöldia* (*Nemodon*) *natalensis*; 6, *Protocardia hillana*; 7, *Veniella forbesiana*; 8, *Trigonia shepstonei*; 9, *Turritella bonei*; 10, *Hemiaster forbesi*.

Lamellibranchs (*continued*)—
Cercomya arcuata (Forbes).
Crassatellites africanus Woods.
,, *haughtoni* Rennie.
Dosiniopsis geversi Rennie.
**Eriphyla lenticularis* (Goldfuss).
Exogyra decussata Goldfuss.
**Glycymeris africana* (Griesbach).
Goniomya umzambiensis Rennie.
**Inoceramus expansus* Baily.
Lima (*Acesta*) *obliquistriata* Forbes.
**Liopistha* (*Psilomya*) *corrugata* Woods.
Macrocallista (*Callistina*) *euglypha* (Woods).
Modiola kaffraria Woods.
,, *typica* (Forbes).
**Neithea quinquecostata* (Sowerby).
**Nordenskjöldia natalensis* (Baily).
Nucula kaffraria Rennie.
Palæomœra haughtoni Rennie.
,, *umzambiensis* Rennie.
Pecten (*Chlamys*) *amapondensis* Griesbach.
Pecten (*Chlamys*) *capensis* Woods.
,, (*Camptonectes*) *kaffraria* Rennie.
,, (*Æquipecten*) *kossmati* Woods.
Pholadomya umzambiensis Rennie.
Pinna vanhoepeni Rennie.
**Pleuromya africana* (R. Etheridge, jun.).
Protocardia hillana (Sowerby).
Solecurtus (*Azor*) *woodsi* Rennie.
Spondylus cf. *calcaratus* Forbes.
**Trigonarca capensis* (Griesbach).

Lamellibranchs (*continued*)—
Trigonarca elongata Rennie.
Trigonia elegans Baily.
,, *shepstonei* Griesbach.
Trigonocallista spathi Rennie.
,, *umzambiensis* (Woods).
Veniella drui (Munier-Chalmas).
* ,, *forbesiana* (Stoliczka).

Gasteropods—
Actæonella (*Trochactæon*) *woodsi* Rennie.
Anchistoma umzambiense Rennie.
Arcotia vanhoepeni Rennie.
Cancellaria meridionalis Woods.
**Confusiscala ornata* (Baily).
Cryptorhytis pseudorigida Rennie.
,, *rigida* (Baily).
Cypræa chubbi Rennie.
**Dicroloma* (*Perissoptera*) *bailyi* (R. Etheridge, jun.).
Eriptycha perampla Woods.
**Gyrodes tenellus* Stoliczka.
Lathyrus (*Mazzalina*) *geversi* Rennie.
Lysis caffra Rennie.
,, *capensis* Rennie.
Margarites (*Solariella*) *radiatula* (Forbes).
Natica (*Lunatia*) *multistriata* Baily.
Nerita kaffraria Woods.
,, *umzambiensis* Woods.
Palæopsephæa kaffraria Rennie.
,, *scalaris* Rennie.
Pirifusus bailyi Woods.
Pirula (*Protopirula*) *capensis* Rennie.
Pseudomelania sutherlandi (Baily).

Gasteropods (*continued*)—
Pugnellus auriculatus Woods.
,, *contortus* (Forbes).
Pyropsis africana Woods.
,, *geversi* Rennie.
**Rostellites capensis* Woods.
**Semifusus* (*Mayeria*) *kaffrarius* Rennie.
Semisolarium bailyi (Gabb).
Trajanella dutoiti Rennie.
Tritonidea (*Cantharulus*) *kaffraria* Rennie.
**Turritella* (*Zaria*) *bonei* Baily.
,, (*Haustator*) *meadi* Baily.

Cephalopods—
Eulophoceras natalense Hyatt.
Gaudryceras amapondense v. Hoep.
,, *cinctum* (Crick MS.) Spath.
,, *kayei* (Forbes).
,, *sigcau* v. Hoep.
,, *tenuilineatum* v. Hoep.
,, *varicostatum* v. Hoep.
Hauericeras gardeni Baily.
,, *rembda* (Forbes).
,, ? *sugata* (Forbes).
Madrasites acuticostatus (Crick MS.) Spath.
,, *africanus* (v. Hoep.).
,, *faku* (v. Hoep.).
,, *natalensis* v. Hoep.
,, *similis* Spath.
Mortoniceras soutoni (Baily).
,, *stangeri* (Baily).
Parapachydiscus antecursor v. Hoep.
,, *simplex* v. Hoep.
,, af. *ootacodensis* (Stolic.).

Cephalopods (*continued*)—
Parapachydiscus umtamfunensis (Crick MS.) Spath.
Parapuzosia haughtoni Spath.
Phylloceras nera (Forbes).
,, *umzambiense* v. Hoep.
,, *woodsi* v. Hoep.
Pseudophyllites indra (Forbes).
Pseudoschlœnbachia griesbachi (Crick MS.) Spath.
,, *papillata* (Crick MS.) Spath.
,, *pseudofournieri* Spath.
,, *umbulazi* (Baily).
Schluteria crassa v. Hoep.
,, *simplex* v. Hoep.
,, *woodsi* Spath.
Spheniscoceras africanum (Crick MS.) Spath.
,, *amapondense* v. Hoep.
,, *minor* (Crick MS.) Spath.
,, *tenue* (Crick MS.) Spath.
,, *umzambiense* v. Hoep.
Tetragonites aff. *cala* (Forbes).
,, *nuperus* v. Hoep.
,, *superstes* v. Hoep.
Diplomoceras indicum (Forbes).
Neocrioceras cf. *spinigerum*, Jimbo.
Oxybeloceras amapondense v. Hoep.
Nautilus sp.
Baculites bailyi Woods.
,, *capensis* Woods.
sulcatus Baily.

Vertebrates—
Teeth of Sharks.
Jaw bones of a pythonomorph reptile, *Tylosaurus capensis* Broom.
Chelonian bones.

Relationships of the Fauna.—The careful collecting done by Gevers from the 40 feet of beds and the descriptions by Rennie, bear out Woods' contention that *only one* palæontological zone is represented, namely the *Campanian*—UPPER SENONIAN—and seemingly the *upper division* thereof, and agree with Spath's conclusion that the cephalopods are mostly comparable or identical with forms that occur in the uppermost Senonian (Upper Campanian plus Mæstrichtian) of Europe. Woods has drawn attention to the moderate relationship with the faunas of the Aryalur and Valudayur of Pondicherry on the east coast of the Indian Peninsula, while Spath has remarked upon the general Indo-Pacific characters of the Pondoland cephalopods. The fauna is further comparable with the equivalent assemblages in Tunis, Angola, Madagascar, Moçambique, and Zululand, but its relationship to the ast will be dealt with later.

B. Natal.—Near the Itongazi River,[1] 8 miles north of the Umzamba, " reefs " of similar beds that have yielded 23 Pondoland species appear at low tide, to find repetition for another two miles near the Umpenyati River. There, a basal conglomerate rests on an uneven surface of granite and carries boulders of granite and well-worn pebbles of sandstone, lydianite, dolerite, etc., followed by calcareous bands full of mollusca, alternating with soft calcareous sandstones containing some Teredo-bored wood, bones and sharks' teeth. Smith Woodward has identified the teeth as closely allied to forms from the Cretaceous of Europe and Pondicherry, while Broom has recorded fragments of the pythonomorph *Liodon* and the plesiosaur *Cimoliosaurus*.[2]

Strata yielding 16 Umzamba species were struck at about 80 feet in the foundations of the Grain Elevator at Congella, Durban, at the inner edge of the lagoon, and presumably correspond to those cut in the deep borehole on the outer side of The Bluff, where the Ecca beds were overlain by 750 feet of deposits, the lower 300 feet at least of which were of Cretaceous age, though the fragments of fossils recovered were insufficient to establish their faunal horizon.[3]

C. Zululand.—Farther up the coast similar strata were pierced in two boreholes a little to the north of the entrance to the Umhlatuzi lagoon beneath 70 and 90 feet of recent sands respectively.

(1) **Umkwelane Hill.**—Senonian beds are well exposed on the low eminence of this name on the southern side of the Umfolozi River at Haig Halt on the Somkele railway. Resting upon tilted Stormberg basalts with a basal conglomerate containing well-

[1] T. W. Gevers and J. de V. Little, 1946, *T.G.S.S.A.*, xlviii, 27.
[2] *Third and Final Rep. G.S. Natal*, 1907, 51, 95, 99, 151.
[3] L. J. Krige, *T.G.S.S.A.*, 1933, xxxv, 48.

worn pebbles of hard rocks derived from all the older formations to the west, they parallel those at Umzamba by their ledges of hard shelly limestone alternating with softer clays, succeeded by buff sandstones and soft dark brown mudstones showing thin ribs of sandstone or limestone and fossiliferous concretions. The latter are well displayed in the old railway cutting whence a giant ammonite 27 inches across was extracted. The total thickness of strata does not exceed 350 feet.

Omitting the less satisfactory determinations, the following fossils have been described from this important locality,[1] those common to the Umzamba fauna being indicated by an asterisk (Fig. 60) :—

Lamellibranchs—
Donax andersoni Eth.
Macrocallista zululandensis Rennie.
Nucula zululandensis Rennie.
Pinna cf. *complanata* Stol.
Semifusus (*Mayeria*) *natalensis* Rennie.
Trigonia umkwelanensis Eth.

Gasteropods—
Actæonina atherstonei Sharpe.
Cylichna fusiliniformis Eth.
,, *griesbachi* Eth.

Echinoid—
Dorocidaris basseæ Bes. and Lamb.[2]

Cephalopods—
**Bostrychoceras* (?) *amapondense* v. Hoep.
Diaziceras tissiotiæforme Spath.
**Mortoniceras* aff. *soutoni* (Baily).

Cephalopods (*continued*)—
**Mortoniceras umkwelanense* Crick.
,, *woodsi* Spath.
Parapachydiscus aff. *colligatus* Binkh.
,, cf. *wittekindi* Schluter.
Placenticeras kaffrarium Eth.
,, *sub-kaffrarium* Spath.
,, *umkwelanense* Eth.
**Pseudoschloenbachia umbulazi* (Baily).
**Baculites bailyi* Woods.
,, *capensis* Woods.
Eutrephoceras aff. *dekayi* (Morton).

Fishes—
Lamna appendiculata Agass.
**Scapanorhynchus* aff. *raphiodon* Agass.

On the general assumption that the Umkwelane and Umzamba deposits are equivalent, one is faced with appreciable faunal differences. Van Hoepen's contention [3] that the Umkwe-

[1] R. Etheridge, *Second Rep. G.S. Nat.*, 1904, 69; G. C. Crick, *Third R.G.S. Nat.*, 1907, 161; L. F. Spath, *Ann. S.A. Mus.*, 1921, xii, pt. 7; J. V. L. Rennie, *Ann. S.A. Mus.*, 1930, xxviii, 236.

[2] H. Besairie and J. Lambert, *Bull. Soc. Géol. France*, 1930, xxx, 107.

[3] *XV Internat. Geol. Congr.*, 1929, Excursion C. 18, 16.

lane strata are the older finds support in the presence of *Placenticeras*, that occurs on the Umsinene River below beds with *Peroniceras* overlain by horizons carrying typical Umzamba species (p. 394). A Middle or even Lower Senonian—*Santonian* or *Coniacian*—age would seem probable, though whether the basal part is as old as Upper Turonian remains uncertain.

(2) **Manuan Creek.**—Lower and Upper Senonian fossils have been obtained at several points in this neighbourhood, notably on the south branch of the creek, on the higher ground just north of its junction with the Umsinene, and again at the north-western corner of False Bay.

The following cephalopods have been described from this area :—*Baculites* cf. *capensis* Woods, *Gaudryceras* cf. *kayei* (Forbes), *G. pulchrum* Crick, *Kossmaticeras* (*Madrasites*) *bhavani* Stol., *Peroniceras* cf. *czornigi* Redt., *P.* cf. *dravidicum* Kossm., *P.* cf. *rousseauxi* de Gross, *Placenticeras* cf. *subkaffrarium* Spath, and *Mortoniceras vanuxemi* (Morton). Probably the following other forms have to be extracted from Newton's list [1] :—*Camptonectes* cf. *curvatus* Gein., *Cytherea* (?) *kaffraria* Eth., *Latiarca natalensis* Baily, *Neithea quinquecostata* Sow., *Protocardia hillana* Sow., *Veniella forbesiana* Stol., and *Gyrodes manuanensis* Newt. The fauna shows close affinities with that of Pondoland.

D. Portuguese East Africa.—(i) This stage is represented in the south at Incomanini on the Komati River 22 miles north-east of Ressano Garcia, where from a gritty sandstone have been described various new species of gasteropods by Cox [2] and of lamellibranchs by Rennie,[3] including a few forms allied to those from Pondoland and suggesting a Mæstrichtian age.

From Inhoca and Sabié on the same river a rather different fauna has been described,[4] containing *Venericardia* (*Cardita*) *beaumonti*, *Crassatella zitteli* and other forms of the Aryalur Stage and indicative of a high Senonian age, while the same species of *Venericardia* has been determined from Mabosi [5] on the Olifants River out of the thick yellowish-red calcareous conglomeratic formation that stretches to the Pafuri River [6] and has released vast quantities of quartzite and other pebbles. East of the Nuanetsi River and along the (northern) Sabi

[1] R. B. Newton, *T.R.S.S.A.*, 1909, i, 1.
[2] L. R. Cox, *Ann. Transv. Mus.*, 1925, xi, 110.
[3] J. V. L. Rennie, *ibid.*, 1936, xviii, 325.
[4] M. Schlosser, *Abh. Bayer. Akad. Wiss.* (Math-Nat., Abt.), 1928, xxxii, 2, 1.
[5] J. V. L. Rennie, *Bol. Serv. Indus. Geol. Moçamb.*, 1935, No. 5.
[6] A. Borges, *ibid.*, 1945, No. 7.

(Save) extend the presumably equivalent red and white sandstones and conglomerates reported by Lightfoot. A similar fauna with *Calyptræa* and *Cerithium* is described by Rennie from Grudeja near the junction of the Revue with the Buzi River.

(ii) The Eocene limestones of the Buzi and Sheringoma plateaux inland from Beira pass down without a clear break into marine Cretaceous of which the top 550 feet consist of soft whitish calcareous clays representing the Danian and Senonian stages.[1] The deeper horizons have only been proved by the deep boreholes sunk for oil on the celebrated Inyaminga (Inhaminga) anticline, a closed structure trending north-east, about 35 miles long by from 1 to 3 miles wide at the surface, with faint seaward dip on the east and steeper landward inclination on the west, where it is in places tilted and dropped down by faulting (Fig. 62). Borehole No. 5, starting about 300 feet beneath the marine beds, proved a great thickness of unfossiliferous strata, namely red grits and sandstones (showing signs of desert conditions)

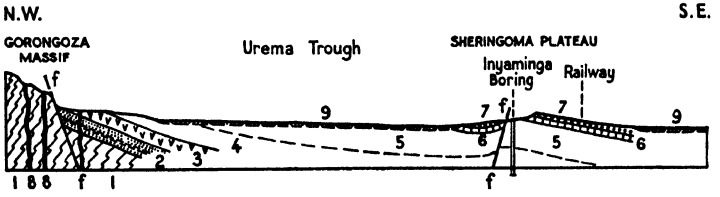


FIG. 62.—Section across the Urema Trough, north of Beira, length about 70 miles. 1, Gneiss; 2, Karroo sedimentary strata; 3, Karroo Basalts; 4, Jurassic (?); 5, Cretaceous; 6, Eocene; 7, Pliocene; 8, Dolerite; 9, Soil and Alluvium; f, Fault.

from at least 600 feet to 2800 feet, pinkish beds to 3400 feet, grits and sandstones (with sparse pebbles of the Lupata volcanics) and clayey and calcareous layers to 7915 feet, and then grey grits and shales with plant fragments to 8083 feet, the depth of the hole. Whether these groups are all of Upper Cretaceous age remains unknown.

Close comparison with the Senonian of the south cannot well be made, for neither ammonites nor nautiloids have yet been obtained from the lower division, the cephalopods being represented by *Baculites* cf. *vagina*, while typical among the other mollusca are *Lopha* (*Alectryonia*) *ungulata* (Schloth), *Gryphæa vesicularis* (Lam.), and *Exogyra decussata* Gold., together with *Neithea quinquecostata* Sow., *Cercomya* cf. *arcuata* (Forbes), *Pugnellus uncatus* (Forbes), *Turritella* cf. *breantiana* d'Orb, etc., only a few of which have been recorded in the Union. The facies, it should be noted, is markedly that of the Ariyalur Beds of southern India.

[1] R. B. Newton, *T.G.S.S.A.*, 1924, xxvi, 130; J. C. S. van Soelen, *Intern. Zeits. f. Bohrtechnik, Erdölbergbau u. Geol.*, 1930, 38th year, 4, pp. 31-6.

V. The Danian Stage

A. Portuguese East Africa.—The upper division in the foregoing area has yielded, in addition to the coral *Ceratotrochus mennelli* Greg., the lamellibranchs *Exogyra lateralis* (Nilss.) and *Gryphæa vesicularis* (Lam.), and the large gasteropod *Rostellaria columbaria* Lam., the nautiloids *Hercoglossa mazambensis* Crick, and *H. sheringomensis* Crick, which possess affinities with both Cretaceous and Eocene forms, and indicate that the strata are the equivalent of the Ninniyur beds of southern India and the Danian of Europe.

B. Needs Camp, Cape.—At the Lower Quarry on the road between East London and Kingwilliamstown, overlooking the Buffalo Valley at 1130 feet above sea-level and forming a tiny patch resting on dolerite, are exposed some five feet of chalky polyzoan limestone containing foraminifera, ostracoda and small shells, nearly all the forms being Cretaceous and suggesting a Senonian or Danian age.[1]

VI. The Non-Marine Upper-Cretaceous

Of great interest has been the discovery of dinosaurian bones from a well over 100 feet deep sunk in the wide sand-choked valley leading down to Henkriesfontein, 30 miles north-east of Steinkopf in Namaqualand.[2] The material consisted of clayey sand with calcareous concretions, some calcified and silicified wood and streaks of lignite, and was probably *in situ*. The bones belong to a form allied to *Camptosaurus* and *Mochlodon*, described as *Kangnasaurus coetzeei* Haughton, pointing to a late Cretaceous age, since dinosaurs are nowhere known to occur in Eocene beds.[3] Non-marine strata of possibly similar age have been reported from near Lüderitz.

From about the beginning of the Jurassic Epoch the interior portion of South Africa has been dry land, wherefore it is a matter of some surprise that more abundant traces of late Cretaceous or of early Tertiary beds should not have been found, despite the very considerable denudation to which the continent has been subjected. It is possible that the very oldest of the deposits in the Kalahari region may date back to beyond the Tertiary, for example certain dark red quartzitic sandstones, pink flagstones, and pale shales in an old channel

[1] The fossils collected have been described by W. D. Lang and H. Woods, *Ann. S.A. Mus.*, 1908, vii, pt. 1; F. Chapman, *ibid.*, 1916, xii, pt. 4.

[2] A. W. Rogers, *T.R.S.S.A.*, 1915, v, 265.

[3] S. H. Haughton, *T.R.S.S.A.*, 1915, v, 259.

50 miles to the north-west of Molepolole ; but in the absence of fossils nothing definite can be affirmed. The presence of *Chara* and *Viviparus* in chalcedonic quartzite beneath the Kalahari sand to the north of Bulawayo in Rhodesia prompted Newton [1] to suggest an Upper Cretaceous age ; but such an antiquity appears unlikely on other grounds (p. 461).

VII. The Cretaceous and Tertiary Volcanics

Symmetrically distributed on both east and west of the continent are a number of occurrences, of alkaline characters chiefly, the ages of which have not been too closely determined, though some are certainly Cretaceous and others Eocene or younger.

(*a*) **East.**[2]—Partaking in the Karroo warping and making an arcuate belt of hilly ground along the Zambezi is the " Lupata Volcanic Series," cut through by that river in the picturesque Lupata Gorge. This rests on a distinctly uneven floor of Karroo or older formations and is divisible into two groups with a break between them, each having a lower division of white, brown, red, or mauve gritty, pebbly, and tufaceous feldspathic sandstones, and an upper one of lavas and tuffs. The lower series of lavas is rhyolitic (Lupata and Mutarara), the upper one alkalic and varied—including trachytic phonolites, porphyritic nepheline basalts, and such rare types as kenyte and leucitophyre (Lupata area).

In the absence of fossils the age of this assemblage cannot definitely be fixed but, since pebbles of the alkaline lavas occur at Inyaminga in strata deemed to be Upper Cretaceous, the Lupata Series has been regarded by Mennell as probably Lower Cretaceous, a view favoured also by Dixey.

No Tertiary lavas have yet been found in this quarter, but a number of small necks of nepheline basalt pierce the Lupata sandstones at, and again 50 miles to the west of, Sená, and according to Mennell the Inyaminga Grit at Inkweyri south of Inyaminga, which would make them of post-Miocene age.

Of uncertain, though apparently post-Karroo, age are the remarkable occurrences penetrating the granite described by Mennell [3] from the Upper Sabi Valley in Rhodesia. At Shawa a ring of syenitic composition 4 miles across surrounds a core of limestone and dolomite, with a reaction-zone of dunite and ijolite (containing nepheline and ægirine-augite) in between. At Dorowa a smaller ring of syenite round lime-

[1] R. B. Newton, *Ann. Mag. Nat. Hist.*, 1920, ser. 9, v, 241.

[2] F. P. Mennell *Geol. Mag.*, 1922, 168 ; *ibid.*, 1929, 529 ; E. O. Teale, *T.G.S.S.A.*, 1923, xxvi, 125 ; E. O. Teale and W. Campbell Smith, *Geol. Mag.*, 1923, 226 ; F. Dixey and W. Campbell Smith, *Geol. Mag.*, 1929, 241.

[3] *Geol. Mag.*, 1946, lxxxiii, 137.

stone is associated with rocks containing vermiculite mica, magnetite and apatite, which are being developed for their phosphate content.

R. B. Young [1] has discovered nepheline syenite-porphyry forming a mass a mile in length at Mount Carminia near Pessene on the Komati Poort-Lourenço Marques railway ; it carries large phenocrysts of orthoclase and small crystals of nepheline and ægirine-augite (Analysis No. 50). Some other allied dykes have been found a little farther to the south and, though their relations to the country rocks are unknown owing to the depth of soil, they must be post-Karroo and either late or post-Cretaceous. The Urema region actually forms the prolongation of the Great Rift Zone of East Central Africa, characterised by an abundance of soda-rich volcanics dating from Cretaceous to mid-Tertiary, and the presence of such types between Delagoa Bay and the Lebombo Range agrees with the view that this great arc of fracturing extends southwards another five degrees.

That extraordinary volcanic vent of the Saltpan north of Pretoria has been described on p. 427, but is mentioned here, since Wagner has suggested that it may perhaps have been as young as Tertiary.

(*b*) **West.**—An instructive province of alkaline rocks, marking probably a zone of subcrustal weakness, extends up the western side of South Africa from Namaqualand into Angola. The age of this is not definitely known, though the majority of the occurrences appear to be post-Stormberg and some post-Cretaceous. The syenite bodies [2] of the Granitberg, Schuleberg, Drachenberg and Naras Hills near Pomona in the Lüderitz littoral are mainly of pyroxene foyaite containing a little biotite and are interesting in that they seem to have melted their way through the folded Nama quartzites, slates, and limestones, the more or less assimilated strips of the invaded rocks having retained their original strike both at the centre and margins of the intrusions in certain cases. The foyaites seem therefore to have reached their present position by a process of magmatic replacement.

A passage through syenite into alkali granite takes place where the mass comes into contact with siliceous strata. Dykes of genetically related foyaite-porphyry, bostonite, etc., are abundant between Pomona and Bogenfels and cut certain dykes regarded as Karroo dolerite.

The area some 20 miles wide embracing the Klinghardt Mountains [3] contains quite a number of occurrences of phonolitic lavas with

[1] R. B. Young, *T.G.S.S.A.*, 1920, xxiii, 98.

[2] E. Kaiser and P. W. F. Beetz, *Die Diamantenwüste Südwestafrikas*, 1926, i, chap. xiii.

[3] E. Kaiser and P. F. W. Beetz, *loc. cit.*, chap. xiv.

associated hypabyssal rocks, the age of which is Tertiary, since at Zwartkop to the east of Bogenfels the former overlie and have metamorphosed the quartzites belonging to the Pomona Cretaceo-Tertiary beds. The latter have also been cut by limburgite in the Chalcedon Tafelberg, while even younger is a pipe occupied by tuff.

In the Rehoboth district Rimann [1] and de Kock found trachytes and phonolites in sills or flows as on the Grosse Spitzkopf, 25 miles to the north-west of Rehoboth. From south of Windhoek, Rimann, Rennie and Gevers [2] have described a number of vents—of which the Regenstein, over a mile across, is the largest—filled with trachytes, phonolites, breccias, and other types together with a host of dykes—igneous, brecciaform, or chalcedonic—radiating from the explosive centres. Silicification of the wall-rocks has in places been extensive.

Intrusives and small effusives of both alkalic and calcic rocks of various kinds and probably different ages occur at intervals in the coastal zone—at Cape Cross, in the Kaokoveld, and Angola. In the opposite direction the extension of this petrographical province is indicated by dykes of bostonite and monchiquite in Namaqualand.

At Lamberts Bay the Table Mountain Sandstone is pierced by a pipe believed by the writer to be half a mile across filled with agglomerate carrying lumps of an olivinitic basalt with 46·32 per cent. of SiO_2 [3], porphyry, etc.

[1] E. Rimann, *Centr. f. Min. Geol. u. Pal.*, 1914, No. 2, 33.

[2] J. V. L. Rennie, *T.G.S.S.A.*, 1927, xxix, 85; T. W. Gevers, *ibid.*, 1934, xxxvi, 77; *Zeits. f. Vulk.*, 1934, xv, 1.

[3] *Ann. Univ. Stellenbosch*, xxii, sect. A, 1944, 56.

CHAPTER XVI

THE VOLCANIC PIPES YOUNGER THAN THE STORMBERG VOLCANICITY

Introduction. Distribution. Pipes and Fissures. Kimberlite. Minerals of Kimberlite. Ultrabasic Inclusions. Basaltic Kimberlite. Micaceous Kimberlite. The Diamond. Melilite basalt Pipes. Breccia-filled Pipes. Pretoria Saltpan. Extra-African Occurrences. Age.

Introduction.—Much subsequent to the extinction of the Stormberg volcanoes, apparently at the close of the Cretaceous Epoch, the earth's crust in Southern Africa was again perforated, the holes thus drilled being filled from below not with basaltic lavas and agglomerates but with the peculiar greenish-blue ultrabasic material known as *Kimberlite, Kimberlite-breccia*, or more familiarly as "*Blue-ground.*"

Of these "PIPES," as they are termed, the first to be discovered was that at Jagersfontein in the Orange Free State in 1870, but those at Kimberley were located shortly afterwards. The finding of diamonds in the highly decomposed material at the surface was responsible for these notable discoveries, though their precise nature was not realised until some time after the mines had been opened up. The first geologist to appreciate their unique volcanic nature was E. J. Dunn, who communicated his opinion to Cohen; a note by the latter, dated 1872, contains the first printed suggestion to this effect.[1]

Since then scores of these "pipes," as well as even more numerous examples of the dyke-like bodies termed "fissures," have been made known and their number is continually being added to. Furthermore, in addition to pipes filled with typical kimberlite, many instances have been made known that are filled with other kinds of material ranging from *purely igneous ultrabasic rock* at one end to *purely sedimentary breccias* at the other;

[1] For an interesting and fully illustrated account of the early discoveries and of the whole history of the Diamond Mines and their working, see *The Diamond Mines of South Africa*, by Gardner F. Williams. P. A. Wagner's monograph *The Diamond Fields of Southern Africa* contains a vast amount of information and has a full bibliography, while in *The Genesis of the Diamond* (2 vols.), 1932, Alpheus F. Williams discusses the subject exhaustively.

while evidence has been forthcoming that has served to link together all these varied, though diverse, types, and to show finally that they resulted from a widespread igneous activity that was manifested most probably near the close of the Cretaceous Epoch. Owing to the intensity of subsequent erosion no traces remain of the original true " craters."

Distribution.—At first it was believed that these pipes were restricted to the area around Kimberley and the adjoining portion of the Free State, but prospecting soon disposed of this idea. Every year pipes are found farther and farther afield, so that they are now known to occur not only in South, but in Central and East Africa, the United States, Brazil, India and possibly Borneo.

Owing to the readiness with which the Blue-ground has crumbled to form soil, there are as a rule little or no surface indications to mark its presence underfoot, consequently there must be scores of occurrences that still await discovery, inasmuch as over wide stretches of country the rocks are covered by superficial deposits. Many of them are never likely to be located owing to the thickness of the cover. Certain " sealed " pipes in Namaqualand and Tanganyika have been detected by the inward tilt of their Tertiary coverings. This fact will have to be borne in mind when the distribution of these volcanic necks is under consideration.

For the present, if we exclude the isolated instances near Heidelberg (Cape) and Robertson, which are the southernmost ones known, the pipes and fissures are spread fairly abundantly over the roughly oval area extending from Namaqualand and Sutherland in the west and south-west to Pretoria in the north-east, but also occur along the Free State-Basutoland border and in East Griqualand, while some occurrences in Gordonia form a link with the group between Keetmanshoop and Gibeon. Much farther to the north-east are those in the Bembesi and Shangani valleys north of the railway from Bulawayo to Gwelo, and beyond these by a great distance the Kundelungu group of Katanga, Belgian Congo, and that of Tanganyika.

There is a very marked tendency for the pipes to occur in *clusters*, so that not unusually the first discovery in a new area leads to the finding of others nearby.

Of such groups one may note those of Kimberley, Barkly West, Koffiefontein, Jagersfontein, Britstown, Sutherland, Namaqualand,

East Griqualand, Pretoria, and Gibeon, the first four of which alone include not less than sixty pipes and dykes. While there is no orderly arrangement of the vents, which are found piercing almost every formation in South Africa older than Upper Cretaceous, there is certainly a tendency for them to run in belts; for example the Barkly West-Kimberley-Koffiefontein-Jagersfontein groups, while a conspicuous chain trending north and south stretches from Grenaat Kop in Prieska to Gansfontein in Victoria West. In the last-named a part of this line coincides with the strike of the hard rocks of the Kheis System, which fact taken in conjunction with observations elsewhere serves to indicate that they have tended to become *aligned along subterranean fractures* in the crust.

Pipes and Fissures.—In size the pipes vary from less than 50 feet up to over half a mile, as in the case of the Premier Mine near Pretoria (Plate XXXVIII), or of the still larger Sungili on the Iramba Plateau in Tanganyika.

As regards the character of their contents there is again an enormous variation. At the one extreme stand such rare types as *Melilite basalt* (*Alnöite* or *Olivine melilitite*) as in Heidelberg and Namaqualand, at the other *Breccias* made up almost entirely of shattered strata explosively disintegrated, as in the Saltpetre Kop group in Sutherland. In some respects intermediate in character comes the abundantly represented class of the *Kimberlites*, which, being of such economic importance, will be considered first; though it must be pointed out that only a comparatively few of them have been found workable, the bulk being either poor in, or else *absolutely barren* of, diamonds.

Mining operations—conducted to the great depth of 3520 feet at Kimberley—have proved that, while the perforation has a tendency towards an oval cross-section, there may be considerable variation not only in its shape but in its size at different levels. A bodily deflection sometimes occurs, as in the Kimberley Mine, the Newlands (near Barkly West) and Kaalfontein (near Pretoria), while the St Augustine's pipe in Kimberley has a twisted course. The Frank Smith Mine in the Harts River Valley has been formed by the coalescence of two contiguous pipes, for it is dumb-bell-shaped in plan. Where mining has gone deep enough, an appreciable contraction of area with depth is universal, a marked exception being the Crown Diamond Mine below the 780-feet level.

The relation between pipes and fissures, as the narrower and

The Premier Diamond Mine. On the farther side is seen the vertical wall composed of felsite against which some kimberlite is still lying. The projecting spur on the right is part of a huge "floating mass" of Waterberg Beds at the foot of which the Blue-ground is cut by dykes of younger kimberlite.

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more dyke-like bodies are called, is a very intimate one. Years ago it was found that "fissure kimberlite" was either poor or barren, wherefore there was some reluctance in admitting "fissure" characters in any prospective mine. With experience, however, it has come to be realised not only that many pipes have dyke-like off-shoots either at the surface or deeper down but that many of them have been developed upon true fissures. They would seem indeed to have taken their origin along some deep-seated joint-plane and to have acquired a less elongated and more circular outline in the higher levels as blocks were torn from the walls of the passage by the explosive action of the gaseous discharges. On passing out of the hard pre-Karroo rocks into the soft Karroo shales a rapid enlargement takes place.

The Roberts Victor Mine near Boshof has two pipes located on a fissure, which in turn swells out considerably at two points along its length (Fig. 63); such local expansions are colloquially termed

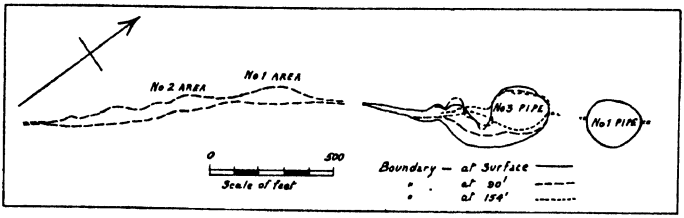


FIG. 63.—Plan of the Roberts Victor Diamond Mine, Boshof. (*After* Wagner and Melvill.)

"blows." Five small pipes are arranged on a dyke 9 miles long near Theunissen in the Free State, while four others, set along a similar narrow fissure, characterise the Newlands occurrence beyond Barkly West. The Colossus Mine near Lochard Station in Southern Rhodesia is now known to consist of three abrupt expansions along a curving fissure traceable for nearly half a mile.

Not uncommonly the pipe is of slightly later age than the fissure on which it stands; less frequently dykes—generally rather narrow ones—cut through the material of the pipe without penetrating its walls; in either case the two kimberlites exhibit lithological differences, while the diamonds from them may display distinctive characters. Some of the fissures are quite narrow yet long, cases being known where they run for miles although only a few feet in width just like an ordinary igneous

dyke, but there is often a swelling out at points; very conspicuous is the turning up of the softer strata along contacts.

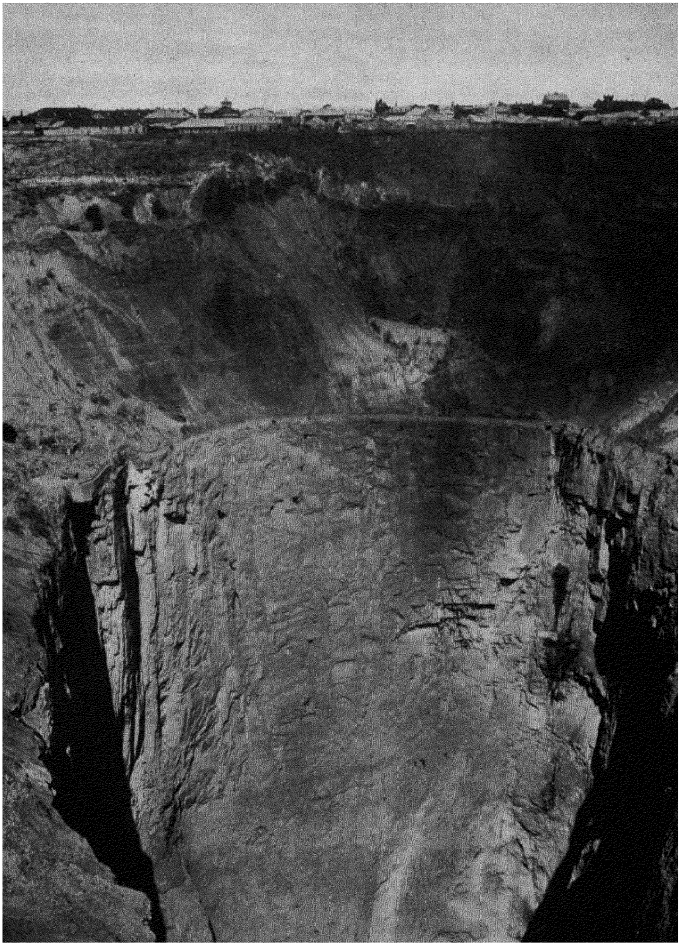
A limited number of fissures have been worked for diamonds down to shallow depths, *e.g.* those at Theunissen and Klipdam (Barkly West), while a few at Zwartruggens on the railway to Zeerust proved remarkably rich although very narrow.

A. The Kimberlite Occurrences

Composite Character.—As obtained from the deeper workings the rock has a dark slaty-blue or bluish-green colour, whence the name "Blue-ground" bestowed upon it. It is moderately soft, is generally greasy to the touch, and shows scattered through a serpentinous groundmass many serpentinised pseudomorphs after olivine, occasional red garnets, grains of brilliant black ilmenite and flakes of brown mica, abundant in some varieties. Most characteristic are the numerous angular and rounded foreign fragments contained therein, predominantly of the country rocks pierced by the pipe.

To this most peculiar material, rich in magnesian silicates, Carvill Lewis gave the name *Kimberlite* and further distinguished three varieties—*kimberlite, a porphyritic ultrabasic lava*; *kimberlite breccia* and *kimberlite tuff*—but these types actually pass into one another by insensible gradations. In this book the term Kimberlite will be employed to include these several kinds, as has indeed been the practice for many years. Wagner on the other hand has introduced the very useful broad subdivision into the *basaltic* and the *micaceous kimberlites*, which form two well-defined classes, though transitional varieties are also known.

There is a general absence of thermal metamorphism on the walls or in the inclusions, indicating that the temperature of the eruptive matter could not have been very high; only a moderate amount of hardening is occasionally noticed, though the included lumps show a peculiar zoning. The phenomena suggest that the magma was largely blown to pieces by repeated explosions, while it must also have been cooled by reason of the considerable amount of fragmental material held up in suspension within it owing to the greater density of the rising column. There are in addition to xenoliths composed of deep-seated ultrabasic and allied types of rock—to be described below—fragments from the granitic foundation of the continent, as well as an abundance of scraps



The Kimberley Diamond Mine, showing the throat in hard, jointed Amygdaloidal Diabase (Ventersdorp); the enlargement above the latter is due to slumping of the soft Upper Dwyka Shales.

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torn from the walls as the pipe was progressively enlarged. Masses were occasionally dislodged from the sides to sink in the kimberlite; these are colloquially known as "floating reef." In certain cases the materials thus enveloped have been derived from *higher* formations pierced by the volcano, but since removed from the area by denudation.

For instance, the kimberlite of the Premier Mine, which is rimmed by diabase, granophyre, and Pretoria beds, encloses a huge tilted mass of red Waterberg conglomerate and quartzite, though that formation is now only seen *in situ* some miles to the north. In the Wesselton Mine at Kimberley, where the highest strata around the pipe consist of the Dwyka shales, blocks of sandstone were found, one with remains of the fish *Acrolepis* and the other showing those of a reptile *Chelyoposaurus*, which prove that the vent must have passed through the Ecca well into the Beaufort Series, though such a horizon is no longer preserved in the immediate neighbourhood. The Norite-encircled pipe on Palmietfontein in the Pilansberg has yielded flakes of Karroo shale having *Glossopteris* impressions. Furthermore, in several of the pipes between Jagersfontein, Postmasburg, and Prieska fragments of amygdaloidal basalt have been discovered, petrologically identical with those of the Stormberg Series of Basutoland, thus indicating that those lavas must formerly have extended some hundreds of miles farther to the west.

Sometimes, as at the Crown (Lace) Mine near Kroonstad, the pipe-material is in parts absolutely crammed with foreign matter; in other places the kimberlite is almost devoid of inclusions and, so to speak, pure. Always conspicuous is the remarkably rounded character of the larger lumps, especially of hard rocks such as dolerite and granite, the churning up of the magma and its contents having so shaped them; the softer shales and sandstones have been more completely pulverised and are found scattered through the blue-ground in angular or sub-angular fragments.

The Minerals of Kimberlite.—There is probably no volcanic rock extant displaying such a variety of mineral content; each new mine is almost a little museum and the profitable hunting ground of the collector. The *minerals* can be classed as:—(1) *Primary*, and (2) *Secondary*.

The *secondary* minerals have in the main been formed from the weathering of the kimberlite or of its inclusions and embrace serpentine, chlorite, calcite and allied carbonates, apophyllite, pyrite, barite, etc. The *primary* minerals can in turn be divided into two fairly distinct groups according to their source:—(*a*) tremolite,

hornblende, tourmaline, rutile, muscovite, apatite, from the granitic rocks pierced in depth by the pipes, but always in small amounts and unrelated to the magma, and (*b*) olivine, enstatite, diopside, chrome-diopside, garnet, phlogopite mica, ilmenite, magnetite, chromite, perofskite, zircon, spinel, sapphire, cyanite, apatite, and the diamond; also melilite and nepheline in the melilite basalt group of pipes (Section B). This assemblage has been derived from the original magma or from basic and ultrabasic holocrystalline inclusions within the breccia, closely allied, however, to the eruptive matter.

The mineral fragments range from grains of microscopic dimensions up to chunks 6 or even occasionally 9 inches in diameter; particularly large garnets, "books" of mica and lumps of ilmenite have been found. There is much variability in the size and kind of the mineral contents from one pipe to another, or even in different parts of the same pipe; some kimberlites, for instance, are rich in garnet, others in ilmenite, some are highly micaceous, and so forth.

Olivine, the most important constituent, is generally idiomorphic, but altered either partially or wholly to greenish serpentine, while a similar change has frequently affected the abundant *enstatite* and scarcer *diopside*. A bright emerald-green *chromiferous diopside* is a striking though rarer ingredient. The bronze-coloured mica is a *phlogopite* rich in magnesia, potash, and iron; the *garnets*, which are blood-red to brown, are magnesia-rich kinds with some alumina and lime, thus approaching pyrope, and vary in shape from irregular to rounded, often with smooth surfaces, but are often cracked; they are commonly though erroneously known as "Cape rubies," just as the lumps of black shiny *ilmenite* are incorrectly called "carbons"; the latter contain some magnesia. The above minerals contain chromium in amounts measurable chemically or spectroscopically. Clear yellowish *zircon*, termed "Dutch bort," is quite common in certain types of blue-ground, derived seemingly from a zircon-pyroxene rock of which rare fragments have been recovered.

Ultrabasic Inclusions.—Conspicuous among the inclusions in kimberlite are certain lumps of coarsely crystalline and sometimes granulitic rocks of high specific gravity ranging from a few inches to a couple of feet in length, generally rather smoothly outlined, but with pitted surfaces.

They consist of nearly all the possible combinations of the minerals olivine, enstatite (and bronzite), diopside, garnet,

phlogopite, ilmenite, and sometimes cyanite, and must have been brought up from great depths within the crust of the Earth. They include remarkable eutectic intergrowths between diopside and ilmenite, between enstatite and garnet, etc. The commonest type is *lherzolite* (olivine-enstatite-diopside-garnet rock), then *hartzburgite* or *saxonite* (olivine-enstatite rock), and more rarely the so-called *eclogite* (more suitably termed *griquaite* by Beck) composed of diopside and garnet. The last is of unique interest since the diamond was first found in the garnet of an eclogite lump from the Newlands Mine in Barkly West as a primary constituent ; more of such finds have been made since, though few of them described.

These varied and so-called " *Cognate xenoliths* " have sometimes been regarded as concretions or segregations that have formed in the magma of kimberlite during or just prior to its solidification, but they are always sharply defined from the blue-ground, their boundaries are not composed by faces of their constituent minerals while their surfaces have suffered attrition ; furthermore, they are holocrystalline and are sometimes foliated and may in addition show the effects of dynamo-metamorphism.

The griquaites are known to belong to a peculiar group varying much in composition, and including granulitic rocks containing occasionally cyanite and graphite and not obviously related to the kimberlites (see Analysis No. 62) ; some carry graphite. That these eclogites represent disrupted material from a deep-seated layer within the Earth's crust and are furthermore of pre-Cambrian age is definitely proved by their Helium-ratios.[1] The ultrabasic olivine-rich xenoliths give on the contrary low values, which is ascribable to loss of helium from those brittle coarse-grained types, so they are probably of high antiquity also and derived from the Earth's ultrabasic zone. It is probable, therefore, that the kimberlite magma itself has originated through local fusion of such crystalline magnesia-rich rocks, with some differentiation thereafter, and that fragments of the disrupted layers were carried up by the magma, becoming rounded by corrosion and attrition during their upward journey. There is weighty evidence for an extraordinary low temperature of solidification.

The Two Classes of Kimberlite.—(1) *The Basaltic Type.*—In this, which is by far the commoner variety, especially among the pipes, one finds in the hand-specimen green olivine in small and large individuals—sometimes up to nearly half an inch across—together with isolated crystals of diopside, enstatite, phlogopite-

[1] A. Holmes and F. A. Paneth, *Proc. Roy. Soc.*, 1936, A, cliv., 385.

mica, and grains of garnet and ilmenite embedded in a serpentinous ground-mass rich in minute crystals of perofskite, apatite, chromite, and magnetite. The olivine generally forms from 50 to 75 per cent. of the rock, but the mica rarely more than 3 or 4 per cent. (Plate XL, 2 *a*).

The structure is porphyritic and the rock can be described as a porphyritic peridotite of basaltic habit. Down to the greatest depths and even in the freshest of samples the ground-mass has been altered to pale greenish serpentine and to calcite, so that its original nature is not known with certainty, though it was probably an ultrabasic glass, as in the limburgites. From this porphyritic type there can be found all transitions through agglomerates and breccias into true tuffs. Along contacts and around inclusions the kimberlite tends to become finer in texture, a feature manifestly due to chilling.

Chemically this rock is characterised by very low silica and alkali, and by high magnesia and water, as shown in Analysis No. 58.

(2) *The Micaceous Type.*—This is generally well represented among the fissures and dykes, some of which, for example those along the Lower Harts and the Vaal River valleys, are highly micaceous; but among the pipes there are quite a number of examples, such as the Colossus Mine in Rhodesia and the Roberts Victor and Lion's Hill mines in the Free State. Mica may indeed constitute as much as one-half of the rock. Holmes has shown that some of this mica has arisen through metasomatic replacement of the other silicates.[1]

In this type one finds corroded crystals of altered olivine and of phlogopite-mica set in a groundmass crowded with mica, augite, apatite, perofskite, and iron ores; there is a base of serpentine and calcite, which must originally have been a glass.

This kind differs from the basaltic type in containing less magnesia but more potash, and is closely related to the lamprophyres and the alnöites (melilite basalts) as shown in Analyses Nos. 59 and 60. Support is thereby given to the view that *the kimberlites belong to the family of the alkali peridotites.*

Wagner has pointed out that there seem to be fairly well-defined provinces in South Africa characterised by the presence of one of these types to the practical exclusion of the other, and that such a province tends to yield diamonds possessing a common stamp.

Weathering of Kimberlite.—Near the surface the rock has almost everywhere been converted into a soft yellowish or reddish

[1] A. Holmes, *T.G.S.S.A.*, 1937, xxxix, 379.

speckled mass known as "yellow-ground." Carbonates of lime and magnesia from the alteration of the silicates impregnate the mass, sending veins and threads through the rock and tending to form a thin shell around each inclusion. Not infrequently hard tufaceous limestone may cap the surface. Below the zone of oxidation, which may range from 40 to 120 feet, the rock becomes bluer and harder—"soft blue-ground"—but possesses the uncommon property of crumbling upon exposure to the weather for a short time and thus releasing the inclusions from their matrix, and consequently setting free the diamond. Still deeper down the kimberlite is darker in colour and harder; but although most of it will usually break down under lengthy exposure, yet portions exist which will defy the elements and will require crushing in order to yield up their valuable contents.

Such a resistant variety is known as "hardebank" or "hardibank" and is represented unfortunately only too abundantly in the majority of mines, while in not a few pipes the rock is predominantly or wholly of this intractable nature; very exceptionally it may actually make an outcrop. Just why one kind of kimberlite should disintegrate, yet another refuse to do so, is difficult to see, since in all varieties the groundmass, and to a large degree the ferro-magnesian minerals themselves, have been converted into serpentinous compounds and calcite principally; presumably, therefore, among such secondary products several different varieties of serpentine must be represented, some of which are more prone to hydration and oxidation. Near the surface replacement by opal may occur.

Serpentinisation of silicates produces considerable increases in the volumes of such minerals; consequently during the gradual alteration of the original kimberlite rock an expansion of the material in the pipes and fissures must gradually have been effected, mainly in the upward direction, the results of which are displayed by brecciation, slickensiding, etc., in the kimberlite itself and particularly along the walls. Such changes were probably in great part effected by the ascension of waters charged with carbonic acid gas at the close of the eruptions, otherwise—unless it be presumed that the carbonate of lime is an original constituent (which is just possible)—it is difficult to account for the abundance of this mineral. Apophyllite, natrolite, and other zeolites have been deposited in cavities accompanied by barite, celestite, pyrite, and marcasite. Such expansion in the superficial zone has produced the upturning of the beds at the contacts.

Owing to its highly decomposed and porous character the yellow-

ground is able to store up water, consequently strong supplies are yielded by every mine, while quite shallow wells along the dykes and fissures are almost invariably successful.

The Diamond and its Origin.—The presence of the gem has naturally been the cause of infinitely wider scientific interest being taken in the pipes and in their contents than would otherwise have been the case; nevertheless even to-day the problem of the origin of the diamond, one of immense attraction to mineralogists still, cannot be regarded as absolutely solved. In the early days of mining at Kimberley it was suggested that the gem might have been formed by the action of the magma on the fragments of carbonaceous Karroo shale so abundantly disseminated through the blue-ground. The finding of barren pipes similarly situated, and of productive ones piercing older rocks and devoid of shale, soon negatived this hypothesis.

To-day there are two main theories :—

(*a*) That the diamond has been derived from the explosive disruption or liquefaction of deep-seated masses of diamond-bearing eclogite (griquaite) and that its presence in the eruptive kimberlite is accidental.

In support of this opinion one can point (1) to the high proportion — probably well over nine-tenths — of kimberlite occurrences devoid of the precious stone; (2) to the numerous broken crystals and cleavage fragments of diamonds in the blue-ground which, in view of the hardness of that element and the softness of the matrix, are difficult to explain except under the known phenomenon of internal strain in the crystals (which some certainly possess and which causes a few of them to burst subsequently); and (3) to the actual occurrence of the gem as a primary constituent in certain garnet-diopside "nodules." Opposed to this is the observation that in many of the productive pipes, *e.g.* the Kimberley Mine, griquaite (eclogite) lumps are excessively rare.

(*b*) That the diamond is an original constituent of kimberlite having crystallised out therefrom.

This view is definitely favoured (1) by the presence of abundant microscopic diamonds in the groundmass of kimberlite; (2) by the notable differences between the stones yielded by neighbouring pipes, by different parts of the same pipe, or by a pipe and its associated dyke—either antecedent or subsequent—such suggesting that each eruption has given rise to a crop of

diamonds with individual characters; (3) by zonal structures and intergrowths of diamond; (4) by inclusion within diamond of another diamond or grains of garnet, diopside, magnetite, zircon or graphite, a frequent phenomenon. Claims to have produced the gem artificially at atmospheric pressure were made by Friedländer, who dissolved carbon in fused olivine, and by Hasslinger, who dissolved graphite in a melt approximating in composition to kimberlite. There remain considerable doubts whether the minute crystals so obtained were truly diamond. According to Shand, Sir Charles Parsons and his colleagues repeated every one of these alleged syntheses and found that only minute spinels were produced. On the other hand Bannister and Lonsdale identified as diamond the tiny crystals which Hannay had claimed were produced by him in 1880 by heating certain oils with metallic lithium.[1]

It would hence appear that, whereas the bulk of the gems must have crystallised out within the rising magma column or, as A. F. Williams has insisted, within the molten matter while still at an immense depth, the remaining small proportion may have been derived through the breaking up of more ancient diamond-bearing plutonic rocks—such as griquaites—a view strengthened by the probability that *kimberlite itself* has been produced by the liquefaction in depth of holocrystalline peridotites and allied rocks such as are revealed to us in the xenoliths of the blue-ground. The carbon composing the diamond can doubtless be referred to such gases as carbon dioxide, carbon monoxide, and methane, it being recollected that kimberlite invariably contains calcite and that this particular phase of volcanicity was dominantly of the explosive type in which gases must have been released at great depths, but under such vast pressures that the overlying crust became pierced by a multitude of relatively small perforations.

B. The Melilite Basalt and Nepheline Basalt Pipes.—Olivine melilitite, as Holmes has preferred to call it, is a rock of considerable density, of highly basic but rare character, yet quite a number of occurrences of it are known in the western portion of the Cape Province, namely at Heidelberg and near Robertson in the very south, in southern Namaqualand (Bushmanland) the north-west, and at Sutherland in between.

[1] F. A. Bannister and K. Lonsdale, *Mineral. Mag.*, 1943, 181, 309-24.

On the farm Spiegel River seven miles north-east of Heidelberg [1] a plug of this kind of rock pierces conglomerates and sandy beds of the Uitenhage Series, and though natural exposures of the junction are wanting, the area occupied can be taken as about 300 yards by 220 yards. The rock exposed at the top of the hill is grey-black and in places rudely columnar; in prospecting trenches it is found decomposed to a pinkish earth.

The rock is remarkably fresh, displaying in thin section (Plate XL, 2 *b*) a brown glassy groundmass in which are set minute crystals of perofskite and magnetite, irregular grains of augite, immense numbers of melilite crystals, and fairly large well-formed phenocrysts of unaltered olivine (see Analysis No. 60).

Suggestive is a pipe six miles to the west on Kruis River—the rock occupying which is considered by Harger to be a kimberlite though thought by Wagner to be more probably a melilite basalt—associated with dykes striking a little west of north of a similar material.[2] Two other occurrences have been reported near Robertson by Taljaard, one of them piercing the Witteberg Series.

The vents on the Sutherland Commonage [3] and the semi-circular dyke partly ringing them in are filled mostly with tuffs containing both igneous and sedimentary matter and either melilite basalt with general characters like those of the Spiegel River rock or a dark coloured, vesicular basic glass containing serpentine pseudomorphs after olivine and some small grains of augite and magnetite. The steam-holes in the latter rock are partially filled with calcite, analcite, natrolite, and other zeolites. Taljaard views these occurrences and also those in Bushmanland as probably sheet-like.

At Matjesfontein nine miles to the south-east of Sutherland there is a pipe filled partly with melilite basalt exhibiting flow-structure and partly with a gritty breccia containing large fragments of granite, quartzite, Karroo dolerite and sediments, mica, ilmenite, and hornblende, the last three constituents serving to connect this occurrence with the Silver Dam type seen nearby (see Section C). Another example on Tonteldoos Fontein close by carries nepheline in addition to melilite and constitutes an important link with a group of sixteen

[1] A. W. Rogers and E. H. L. Schwarz, *Ann. Rep. G.C. for* 1899, 55; M. S. Taljaard, *T.G.S.S.A.*, 1937, xxxix, 282, Fig. 1.

[2] H. S. Harger, *T.G.S.S.A.*, 1922, xxiv, 1.

[3] A. W. Rogers and A. L. du Toit, *Ann. Rep. G.C. for* 1903, 43; *T.S.A.P.S.*, 1904, xv, 61.

pipes situated on a fracture pattern far to the north-west in Namaqualand a little to the east of the Kamiesberg.[1]

These bodies piercing the gneiss vary from 45 yards to 750 yards across but have rather irregular outlines, and are composed of black nepheline basalt or nepheline-melilite basalt with a specific gravity ranging from 3.23 to 3.27. In thin section they show characters much like those of the aforegoing, the crystals of fresh olivine being embedded in a groundmass made of small crystals of melilite, nepheline, red biotite, perofskite, and sometimes of brown glass (Plate XL, 2 *c*). In two cases the infillings included both melilite basalt and kimberlite breccia.

From an undoubted pipe on the boundary between Gamoep and Koppieskraal a small diamond was discovered in a breccia which, although devoid of melilite, is shown by the higher percentage of silica and lime and lower proportion of magnesia to be intermediate between the kimberlites and melilite basalts.

C. The Breccia-filled Pipes.—Of these the finest examples are furnished by the Saltpetre Kop group and the Geitsi Gubib.

Saltpetre Kop is a conspicuous peak in the Sutherland district rising about 1000 feet above the general level and composed of breccias and tuffs, which fill an irregularly shaped neck about 1000 yards long by 600 yards wide. The Beaufort beds, which the vent traverses, are nearly horizontal in this region, but at a distance of about a mile and a half show a dip away from the pipe, which inclination increases as the neck is approached until just around the breccia plug the beds are standing nearly vertically. Grouped around this central volcano, though not materially disturbing the regularity of the qua-qua-versal dip, are nineteen " satellitic " pipes and forty-six dykes filled mostly with breccias or fine tuffs.

Petrologically their contents vary greatly, but all consist in the main of shattered sedimentary rocks (chiefly Karroo) set in a matrix of similar comminuted material; in addition there are pieces of granite, gneiss, mica schist, quartzite, and dolerite, also some fragments of brown mica, hornblende, and ilmenite, just as in the breccia at Matjesfontein. In places the breccias and tuffs have been strongly impregnated with carbonates of lime and magnesia, barite, limonite, and silica, more particularly in the smaller pipes and in the peripheral portion of the main vent, while the up-tilted sandstones and shales have been similarly hardened and impregnated. Doubtless this mineralisation was

[1] A. W. Rogers, *Ann. Rep. G.C. for* 1911, 61; M. S. Taljaard, *T.G.S.S.A.*, 1937, xxxix, 291; T. W. Gevers, *P.G.S.S.A.*, 1937, xxxix, p. xciv.

effected by heated waters ascending through the porous fragmental materials towards the close of the eruptions, as happens during the " solfataric " stage in recent volcanoes.

The doming-up of the strata is an extraordinary feature and very strongly suggests the existence of a buried laccolithic igneous mass, which arched up the overlying beds before relief was afforded, by the drilling of holes through the stretching cover and the violent discharging of heated gases through the perforations thus produced. Recalling the neck partly filled with agglomerate and partly with melilite basalt on Matjesfontein right on the edge of the domed-up area and the nepheline-melilite basalt pipe on Tonteldoos Fontein but little farther away, it is not going beyond the bounds of speculation to suggest that this hypothetical laccolith would be composed of alnöite or some allied rock.

The pipe on Silver Dam close by contains breccias with a serpentinous matrix in which are set xenolithic fragments, and pieces of hornblende, mica, ilmenite, and garnet; under the microscope perofskite is seen and serpentine pseudomorphs after olivine. The most important feature lies in the suite of granulite inclusions composed of monoclinic pyroxene, brown hornblende and mica, ilmenite, garnet, and some feldspar, for they at once recall the similar xenoliths so abundantly represented in many of the kimberlite pipes in the Northern Cape.

On De Vrede, Portugals River, and Blaauw Blommetjes Keep in this neighbourhood there are various breccia-filled pipes and dykes; while on the last-named farm a sheet-like mass of breccia cuts through a dolerite sill, thus corroborating the evidence of post-Karroo age afforded by boulders of that rock in the agglomerates.

Three small necks of this type occur together on the boundary between Kaffirs Kolk and Grenaat Kop in Prieska filled with breccias composed almost entirely of indurated fragments of the Dwyka Series through which the pipes pass, but there are also fragments of an igneous rock allied to blue-ground. Grenaat Kop itself and the ridges to the south are made of shales that have been silicified, evidently through heated water ascending along numerous lines of fracturing in the strata. Situated on this belt of fracturing and alteration are the three pipes and at least three dykes of kimberlite with a similar north-north-westerly trend.

A large agglomerate-filled pipe penetrates the Malmesbury slates of the Kobe Valley in Van Rhynsdorp; through the dark-red matrix fragments of granite, quartzite, crystalline limestone, etc., up to 8 feet in length are distributed promiscuously.

Conspicuous from afar, in South-West Africa, is the Geitsi Gubib or Gross Brukaros Mountain, two miles in diameter, that

rises abruptly to a height of 1800 feet above the extensive flat between Berseba and Gibeon. As at Saltpetre Kop the horizontal strata—here the Fish River Beds—show an arching up a mile or more away from the pipe, but near the boundary of the latter the inclination reverses and they come to dip inwards. Rogers [1] has commented upon the remarkably crater-like aspect of the mountain, although the "rim" of the feature is actually due to a ring of hard breccias and tuffs dipping in towards the central hollow underlain by softer fragmental material.

The coarser breccias are red and brown, the finer rocks rather paler, while some show silicification. Fragments of shale and red and black jaspery rocks predominate, together with sandstones, quartzites, diabase, and gabbro and pieces of feldspar. The presence of several small satellitic pipes and the existence of barite in the breccia form points of resemblance with Saltpetre Kop. The age of this volcanic centre has not definitely been made out, but several features indicate a post-Karroo date. Particularly suggestive is the fact that kimberlite pipes are numerous in the immediate neighbourhood.

D. The Pretoria Saltpan.—The crater-like feature called by this name 25 miles to the north of Pretoria is unique (Plate XL, 1). Possessing a diameter of two-thirds of a mile, it is about 400 feet in depth, yet with its floor sunk nearly 200 feet below the level of the surrounding flat country as indicated in the cross-section (Fig. 64). Piercing the Red Granite, its rim is partly

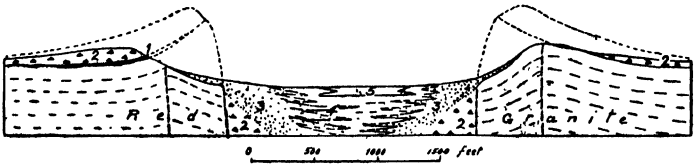


FIG. 64.—Hypothetical section through the Saltpan: 1, Grits; 2, Granite breccia; 3, Granite detritus passing into 4, Laminated saline clays; 5, Muds carrying carbonate of soda. (*After* Wagner.)

built up of granite blocks ejected by the volcano, and between this breccia and the solid granite-foundation there intervene at a few points certain grits that indicate the original land-surface when the volcano came into action. The precise limits of the central perforation are invisible, since the inner slopes are made by debris and the centre is occupied by a pan on dark sticky muds in which water collects after rain, the liquid becoming

[1] *T.R.S.S.A.*, 1915, v, 247.

strongly impregnated with the chloride and the carbonate of soda. Boreholes have proved a layer of muds with trona (the hydrous double carbonate and bicarbonate of soda), then a layer rich in crystals of gaylussite (the hydrous double carbonate of soda and lime), and below this a thickness of dark saline clays to the depth of 230 feet, without striking any solid rock.

The Saltpan is of economic importance as a source of both salt and carbonate of soda, these substances being separated from the liquor pumped from the boreholes.

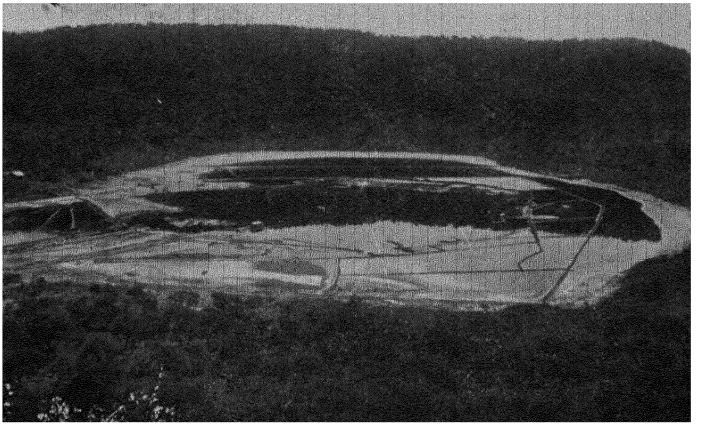
Wagner,[1] who has minutely studied and described this extraordinary occurrence, has shown that the granite was primarily domed-up as in the Saltpetre Kop vent, but that the central part must have subsided after the drilling of the chimney ; he designates the feature a " sunken caldera." Of the materials filling the pipe, apart from masses of granite only some blocks of norite and peculiar alkaline syenites and porphyry have been found, together with some of an extraordinary dolomitic breccia, containing magnetite and fragments of chlorite schist, possibly of igneous origin. The precise nature of the hidden eruptive matter remains a matter for speculation. The occurrence is certainly of post-Karroo age and is regarded by Wagner as comparatively young, possibly late Tertiary. According to him the evidence points to the sodium compounds having originated through magmatic vapours and solutions during the concluding stages of volcanic activity. Bond,[2] however, views the brine as merely a highly concentrated ground-water since the supplies from the Red Granite carry typically sodium chloride and carbonate, and in about the same proportion.

Relationships of Types.—*Extra-South African Occurrences.*—The preceding is merely the briefest of summaries of the numerous and extremely varied occurrences. Although divisible into the three widely differing classes, the existence of linking types indicates their truly intimate relationships and suggests that they are but the diverse manifestations of a single, widespread volcanicity in which the deep-seated ultrabasic shell of the Earth's crust was involved.

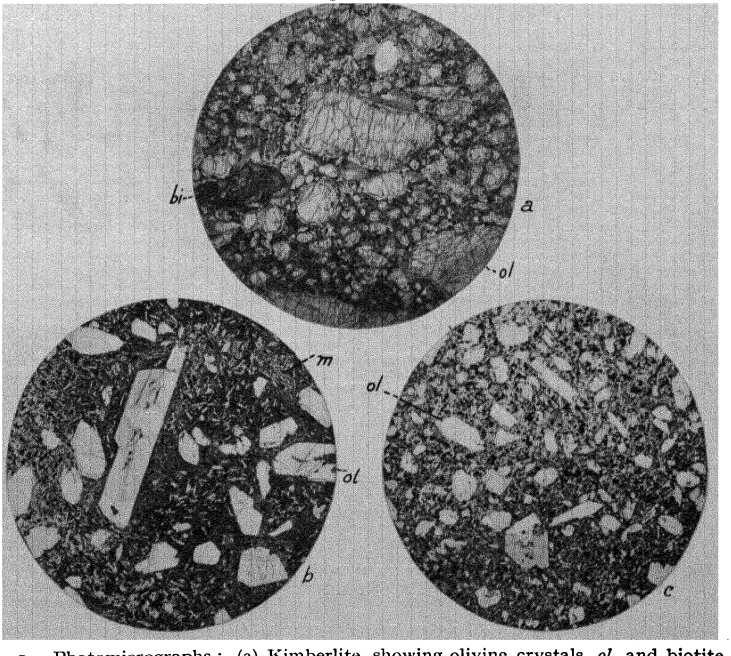
It will be observed that micaceous kimberlite differs from the basaltic variety in containing more potash and alumina and that the melilite basalts and nepheline-melilite basalts show fairly high alkalies, lime, and ferrous iron, but much less magnesia. When the individual variations are taken into account, it becomes possible to arrange the rocks so that a full sequence is formed ranging from melilite basalt to

[1] P. A. Wagner, *Union S.A.G.S.*, Mem. 20, 1922, wherein the previous literature is cited.

[2] G. W. Bond, *Union S.A.G.S.*, 1946, Mem. 41, 47.



1.—The Saltpan north of Pretoria.



2.—Photomicrographs : (a) Kimberlite, showing olivine crystals, *ol*, and biotite, *bi* ; (b) Melilite basalt, showing porphyritic olivines, *ol*, and lath-shaped crystals of melilite, *m* ; (c) Nepheline basalt with porphyritic olivines, *ol*. Each magnified 10 diameters.

[*Face page* 428

kimberlite and the latter will thus fall in the group of the *alkaline peridotites*. There is indeed some support for the suggestion, first made by Carvill Lewis, that kimberlite is an extremely altered variety of melilite basalt despite certain differences in chemical composition.

The fascinating problem of kimberlite, with its relations to other eruptive types and its bearing on the constitution of the Earth's crust, has been reviewed by P. A. Wagner, A. F. Williams, and most recently by A. Holmes.

This eruptive phase was, moreover, not confined to Africa but was developed elsewhere, though sporadically. Of more than usual interest are the peridotites and peridotite breccias of Arkansas [1] in the United States, practically identical with kimberlite and sometimes carrying diamonds, for instance near Murfreesboro; elsewhere dykes of similar rock have been discovered, *e.g.* in Elliot Co., Kentucky and at Ithaca, Mannheim and Syracuse in New York State, it being instructive to find melilite in two of them in the last-mentioned locality.

In Brazil several pipes piercing Triassic sandstone around Patos in western Minas Geraes are filled with breccias containing typical kimberlitic minerals. The majority of the well-known diamondiferous occurrences in this State are of much greater antiquity. New South Wales has brought to our knowledge two pipe-like occurrences containing diamonds, garnet, and chrome-diopside, one a doleritic rock from Inverell and the other an agglomerate from Bingara.[2] Certain pipes in India also carry diamonds.

Age of the Occurrences.—No pipe or fissure belonging to any of the various types has been found to be earlier than the Karroo dolerite. The occurrences in Sutherland help to connect the group with the melilite basalt known to pierce the Lower Cretaceous in the Heidelberg district (Cape). The announcement by Harger of kimberlite also cutting the latter and of vertical dykes traversing those tilted beds shows that the Cretaceous strata had already been flexed and faulted. Such movements were completed only just before the Senonian. The Kruis River pipe, however, is apparently older than the Surface Quartzites of the high-level terraces, which are perhaps of Eocene age. The volcanicity would consequently date to some time between the Senonian and the Eocene and belong most probably to the *close of the Cretaceous*. Such accords well with the age-determinations of 58 and 51 million years for kimberlite and melilite basalt respectively obtained from the helium-ratios.[3] In Arkansas, the diamond-bearing peridotite pierces Lower Cretaceous sediments, but is overlain unconformably by those of Upper Cretaceous age.

[1] H. D. Miser and C. D. Ross, *Ec. Geol.*, 1922, xvii, 662.

[2] J. A. Thomson, "The Diamond Matrices of Australia," *Geol. Mag.*, 1909, 492.

[3] A. Holmes and F. A. Paneth, *Proc. Roy. Soc.*, 1936, A, cliv., 385.

CHAPTER XVII

THE TERTIARY AND QUATERNARY FORMATIONS

Introduction. Marine Deposits. Portuguese East Africa. South-West Africa. Alexandria Formation. Raised Beaches. Drowning of the Coast. Terrestrial Deposits. Surface Limestone. Surface Quartzite. Lateritic Ironstone. High-level Gravels. Knysna Beds. Kalahari Beds. Kalahari Sand. Low-level Gravels. Pans.

Introduction.—Over areas totalling 40 per cent. of South Africa the hard rocks, from the oldest up to the Cretaceous, are concealed by unconformable deposits of sands, gravels, limestones, etc., that belong to a comparatively recent order of things and that are yet in the process of accumulation in some localities.

Of those that are *marine*, as shown by their fossils, some date back to the beginning of the Tertiary Era ; others are younger, though the collecting done has been insufficient to establish their precise age, while the more recent ones contain forms of mollusca still living along the coast.

The bulk, however, are *terrestrial* and, though their degree of induration and erosion indicate a considerable antiquity, no clear dating can be assigned usually, since they have yielded but few fossils, mainly mammalian bones belonging sometimes to extinct species, or land shells of kinds still living in the neighbourhood.

A great handicap is the absence of any clear records of the Great Ice Age which left so strong an impress on life in the Northern Hemisphere. The key must therefore be sought in more finds of mammalian remains in intimate association with marine mollusca, two cases of which are already known. The relative ages of the various deposits, commonly called " Superficial," of this continent have consequently to be based upon their general lithological characters, state of erosion, relative heights above valley-bottom or sea-level—as for example in the case of the High-Level Gravels or the Ocean-controlled Terraces of the Southern Cape—or else the inclusion of artefacts. To the geologist with European experience the absence of the familiar till or boulder-clay, and the presence of such novel types as the surface limestones, etc., are disconcerting, wherefore the latter have demanded treatment at some length.

Though detailed chronological arrangement of the various superficial deposits within this enormous area is not yet feasible, the great advances made recently have enabled much to be done, but many uncertainties still remain. While, as compared with East or Central Africa, the part played by *Igneous Rocks* is insignificant, lavas and intrusions of similar types are now known from both the eastern and western sides of South Africa.

1. Marine Deposits Mainly

A. The Eocene, Miocene and Pliocene Beds of Portuguese East Africa [1]

1. In the north-east the Cretaceous beds are succeeded with seeming conformity by massive white or creamy *Nummulitic Limestones* fully 600 feet thick that build up the Sheringoma and the Buzi plateaux to the north and west of Beira, rising to 1100 and 800 feet above sea-level respectively. These tablelands, which slope gently seawards, display numerous fissures and sink-holes, but on their inland sides break off in scarps, while about Inyaminga (Inhaminga) the limestones are bent over into a monocline and dropped down on the north-west by local faulting, to disappear beneath the higher formations and the soil-covered plains beyond (Fig. 62). The limestones occur at Estaquinha on the Buzi River 45 miles west of Beira (de Carvalho).

The fossils (Fig. 65) include the foraminifera *Nummulites biarritzensis, N. perforata, N. guettardi, N. planulata, N.* cf. *variolaria, Orthophragmina* cf. *pratti* (formerly identified as *Orbitoides papyraceus*), *Operculina,* the echinoid *Conoclypeus* cf. *conoideus,* and a large *Campanile.* These indicate a Middle Eocene (Lutetian) age, several of those species being known from Madagascar and India.

2. About Inyaminga these limestones are followed by red and purplish sandy beds containing small oysters and considered as of Miocene age, being overlain unconformably by the thick Inyaminga grits—conglomeratic in places—with *Turritella,* viewed as Pliocene. All these strata have shared in the local up-doming.

3. To the Lower Miocene Cox [2] has ascribed calcareous deposits at Inharrine and Mongué near Inhambane and at Delagoa Plantation on

[1] E. O. Teale, *T.G.S.S.A.,* 1924, xxvi, 103, with descriptions of the fossils by R. B. Newton; J. C. S. van Soelen, *Intern. Zeits. f. Bohrtechnik, Erdölbergbau u. Geol.,* 1930, 38th year, 4, p. 31. Additional information has been supplied by P. de Carvalho and A. Borges.

[2] L. R. Cox, *Serv. Indus. Min. e. Geol. Moçamb.,* 1939, Bol. No. 3.

the Komati River 45 miles north of Lourenço Marques, and to the Pliocene some beds at Morrumbene near Inhambane with a fauna rather like that from the Zwartkops River, Cape. To the Miocene Schlosser has referred certain fossiliferous limestones on the Maputa and Tembe rivers, near Delagoa Bay.[1]

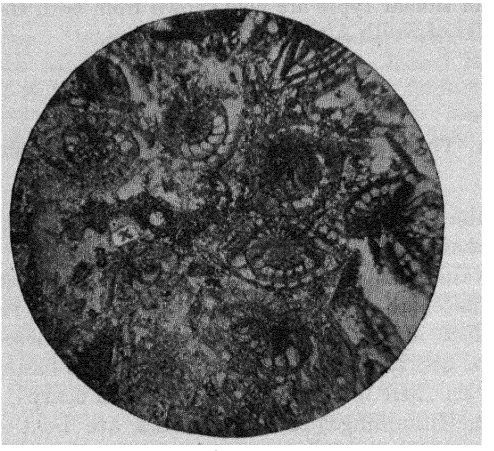


FIG. 65.—Thin section of Eocene foraminiferal limestone from Sheringoma, P. E. Africa, showing *Nummulites* cf. *variolaria* Lam., and *Orthophragmina* cf. *pratti* Mich. (indicated by a ×), ×10. (*After* Bullen Newton.)

B. A Miocene Marine Fauna from Zululand

[*Editor's Note.*—During 1952 Dr L. C. King discovered a richly fossiliferous sandstone in Zululand. The account which follows has been contributed by Dr King.]

A richly fossiliferous sandstone of Burdigalian (early Miocene) age crops out on the Umfolozi River about nine miles from the sea. The beds, of which about fifty feet are exposed in the hill at Uloa, dip gently seaward at an angle of about one degree. The formation represents a Miocene sandbank across which browsed hordes of shell-fish of both vegetarian and carnivorous habits. So abundant was the animal life that traces of petroleum appeared in the matrix when some of the fossils were cleaned. This record is especially interesting as borings for oil are at present being made into beds of similar age at Inharrime, north of Lourenço Marques.

[1] M. Schlosser, *Abh. Bayer. Akad. Wiss.* (Math-Nat. Abt.), 1928, xxxii, 2, 1.

The fauna is strongly Indo-Pacific in type, being very similar to that at Fundi Isa in Kenya, at Pemba, in North-West India, in Burma and in Java. There are but few links with Tertiary marine faunas of the Cape or of South-West Africa.

The foraminifera have not yet been studied in detail, but the following genera have been identified, either by Mr P. G. Biesiot of Moçambique Gulf Oil or by me: *Lagena, Nodosaria, Globigerina, Textularia, Amphistegina, Canceris, Cibicides, Eponides, Operculinella* (?), *Quinqueloculina* and *Rotalia.* The assemblage, Mr Biesiot informs me, is similar to that at Inharrime to which a late-Oligocene or early-Miocene age is assigned.

Among other invertebrate groups the following species have been identified:

Echinoids.
Cidaroid spines.
Temnopleurus toreumaticus (Leske).
Clypeaster martini Desmoulins.
„ *profundus* d'Archiac and Haime.
Laganum depressum Agassiz.
Echinolampas jacquemonti d'Archiac and Haime.
„ *spheroidalis* d'Archiac and Haime.

Lamellibranchs—
Nucula dowlingi n. sp.
„ sp.
Cucullæa concamerata Bruguiere.
Scapharca inæquilateralis Guppy.
„ *prænatalensis* n. sp.
Glycymeris africana Cox.
Ostrea hyotis Linne.
„ *hyotiformis* Philippi.
„ *angulata* Sowerby.
Crassostrea prismatica Gray.
Sectipecten vasseli (Fuchs).
Æquipecten uloa n. sp.
Chlamys senatoria Gmelin.

Lamellibranchs (*continued*)—
Chlamys puzio Linne.
Amussium umfoloziana n. sp.
Spondylus sp.
Lima lima Linne.
Placuna anomala n. sp.
Modiolus cf. *capensis* Krauss.
Modiolaria excavata n. sp.
Crassatellites cf. *sulcatus* Solander.
Lucina neosquamata Noetling.
Loripes clausa (Philippi).
Cardium papyraceum Chemnitz.
Trachycardium cf. *sindense* Vredenburg.
Macrocallista erycina Linne.
Antigona granosa Sowerby.
Marcia (*Levimarcia*) *paupercula* (Dillwyn).
Tapes sulcaria Lamarck.
Tellina (?) *regularis* Smith.
Gari elongata n. sp.
Teredo (*Kuphus*) *polythalamia* Linne.
Corbula socialis Martin.
Solen capensis Fisher.

Gasteropods—
Cynisca formosa Turton.

Gasteropods (*continued*)—
Architectonica cf. *perspectiva* Linne.
Natica callosa Sowerby.
Polinices cf. *mamilla* Linne.
Turritella aff. *carinifera* Lamarck.
,, cf. *capensis* Krauss.
,, *angulata* Sowerby.
Vermetus sp.
Strombus altispirus n. sp.
,, *floridus* Lamarck.
Seraphs naricum Vredenburg.
Trivia cf. *ornata* Lamarck.
Cypræa aff. *citrina* Linne.
Cassis cf. *mombasana* Cox.
,, *achatina* Lamarck.
Tonna luteostoma Küster.
,, *nkulunkulu* n. sp.
Ficus cf. *condita* Brong.
Ranella elegans Beck.
Calliophora violacea Kiener.
Pyrene cf. *pardalina* Lamarck.
Nassarius kraussianus, Dunker.
,, *delislei* n. sp.
,, (*Hima*) *tringa* Sowerby.
Galeodes kehla n. sp.
Streptosiphon pyriformis Kaiser.
Fusus prolongata Turton.

Gasteropods (*continued*)—
Latirus pseudolynchoides Vredenburg.
,, *indicus* Vredenburg.
Turbinella premekranica Vredenburg.
Mitra textura Lamarck.
Voluta ponderosa Turton.
Harpa (*Eocithara*) *narica* Vredenburg.
Oliva australis Duclos.
Olivella (*Callianax*) *martiniopsis* n. sp.
Ancilla glandiformis Lamarck.
,, *glabrata* Linne.
,, *ntombazana* n. sp.
Baryspira impi n. sp.
,, *shaka* n. sp.
Cancellaria govenderi n. sp.
" *Drillia* " *curiosa* n. sp.
Crassispira (*Inquisitor*) *coxana* n. sp.
Clionella inornata n. sp.
Conus (*Lithiconus*) *litteratus* Linne.
,, (*Chelyconus*) *haughtoni* n. sp.
,, *proliferatus* n. sp.
Ringicula turrita Martin.
Kaitoa islandica Marwick.

Teeth of the giant Miocene shark *Carcharodon megalodon* are also present. Corals are represented by *Flabellum distinctum* Milne-Edwards and *Ceratotrochus alcockianus* Noetling, and bryozoa by *Retepora cellulosa* Linne. Barnacles of a species allied to *Balanus amphitrite* Darwin are common, and Neptunid crab carapaces occur rarely.

C. The Eocene-Miocene of South-West Africa

Along the Lüderitz littoral patches of strata are preserved, certain of which contain marine fossils, that demonstrate the former wide development of deposits laid down in valleys during a Tertiary submergence of the coastal region. Special interest

attaches to them because they *contain diamonds*; indeed the remarkable diamondiferous sands worked in this territory appear to have been largely derived from the disintegration of these older sediments (see p. 517).[1] Another striking feature has been the discovery in them of bands carrying vertebrate remains. Their base descends into hollows in the older rocks, as can be seen close to Lüderitz or at Elizabeth Bay, but to the south in the neighbourhood of Bogenfels they make a series of well-defined terraces or raised beaches, the oldest attaining an altitude of over 500 feet above the sea, the most recent lying at tide-level. They consist of grits with occasional pebbles, sandstones enclosing irregular layers and patches of chalcedony, and lime-cemented gravels with pebbles of variously coloured agates, brown and red jasper, and chalcedony.

The marine beds are restricted to the tract between Pomona and Buntfeldschuh, the greenish sandstones of some of the terraces near Bogenfels having yielded *Ostrea subradiosa*, *Turritella kaiseri*, and *Aturoidea* (*Aturia*) *lotzi* among the mollusca, also teeth of sharks. Described originally as Lower Miocene, more extensive collecting has shown that the fauna is *Upper*, possibly even *Middle Eocene*.[2] The presence of *Mya* (*Rhætomya*) *schweinfurthi* and *Crassostrea roncana*, together with the fish remains, indicates close affinities with the Eocene (Mokattam) of Egypt, of Nigeria, and of Angola, while the alliances seem to be also with the Patagonian Eocene.

Under the name of *Pomona Beds*, Beetz[3] has placed certain silicified strata of the Lüderitz littoral which rest on an ancient surface of supposed Nama beds that was developed under arid conditions. Embracing calcareous sandstones, limestones, and quartzitic sandstones, though mainly a hard pale silcrete (p. 447), this formation forms cappings such as the "Chalcedon Tafelberg," where it is cut by an intrusion of limburgite (originally identified as melilite basalt). Though provisionally regarded by Beetz as late Cretaceous, or Lower Eocene at latest, no fossils have been found in the overlying presumed Eocene beds, while it has yielded only an extinct species of land-shell, *Dorcasia antiqua* Wenz.

[1] P. A. Wagner, *Union S.A.G.S.*, Mem. 7, 1916, 74; E. Kaiser, *Die Diamantenwüste Südwest-Afrikas*, 1926, ii, chap. xviii.

[2] H. Lotz, J. Böhm, and W. Weissermel, *Beit. z. geol. Erfor. Deut. Schut.*, 1913, Heft 5. (The original determination may prove closer to the truth.)

[3] E. Kaiser, *Die Diamantenwüste Südwest-Afrikas*, 1926, ii, chap. xviii.

It is not unlikely that the so-called " Pomona Quartzite " will be found to include similar materials of widely different ages.

Cappings occur at intervals along the coast, as at Chameis, Alexander Bay, and the mouth of the Buffels River, while from just north of the Olifants River mouth Reuning [1] has described an 80-foot raised beach with basal layer carrying sharks' teeth, *Kraussina lata* and other shells, followed by from 3 to 5 feet of silicified sand and grit—viewed as the equivalent of the Pomona Quartzite—and overlain by beds with *Ostrea prismatica* Gray, but the precise horizon of the Tertiary denoted by the lowest beds is uncertain.

The grey marly sandstones from the younger fluviatile strata near Bogenfels have furnished fragments of bones belonging to a large number of animals, among which are represented the rhinoceros, two antelopes, a variety of pig, various hyracoids, rodents, and other small forms. According to Stromer [2] the fauna is *Lower Miocene* or perhaps Upper Oligocene. Interest centres in the fact that one of these, *Myohyrax ostwaldi* Andrews, is known from the Miocene of Victoria Nyanza in East Africa, while another, *Protypotheroides beetzi* Stromer, is allied to a form from Patagonia; furthermore, the assemblage indicates a steppe climate. These valuable discoveries supply the first glimpses of vertebrate life in South Africa during the mid-Tertiary.

D. The Alexandria Formation—Eocene-Pliocene—of the Cape

The white marine limestones to the south of the Zuurberg Range—indicated on A. G. Bain's map of 1856 as " Tertiary "—were thus named by Schwarz only in 1909 from their development in the Alexandria district.[3] Equally widespread and all but identical are those described as the Bredasdorp Formation by Wybergh [4] that form its westward continuation.

(*a*) Within this 600 mile stretch they rest upon a pre-Tertiary surface that, rising inland at from 40 to 70 feet per mile, cuts across all the older formations, including the Uitenhage Series. Elevation of the coast and erosion by the various transverse rivers have left a row of outliers, from Needs Camp near East

[1] E. Reuning, *T.R.S.S.A.*, 1931, xix, 205; S. H. Haughton, *T.G.S.S.A.*, 1932, xxxiv, 31.

[2] F. Stromer, *Sitz. Bay. Akad. Wiss. Math.-phys. Kl.*, Dec. 1921, 1922; *ibid.*, Dec. 1923, Munich.

[3] E. H. L. Schwarz, *T.G.S.S.A.*, 1909, xii, 107. For general accounts, see A. W. Rogers, *Ann. Rep. G.C. for* 1905, 9; S. H. Haughton, *Union S.A.G.S.*, 1928, Expln. Cape Sheet 9; E. D. Mountain, *ibid.*, 1946, Expln. Sheet 136.

[4] W. Wybergh, *Union S.A.G.S.*, 1920, Mem. 11, ii; *T.G.S.S.A.*, 1920, xxii,

London in the east to Saldanha Bay in the west, of which the largest are those situated between Bushmans River and Uitenhage, and between Mossel Bay and Cape Agulhas, though extending back nowhere for more than 20 miles and usually for less than 10 miles. East of Bathurst they have become reduced to tiny cappings. The altitude of their inner limit is 1200 feet at Needs Camp, 900-1000 feet between Bathurst and Sandflats, 400-500 feet in Riversdale district, 150-250 feet in Bredasdorp district and still less beyond. The outer edge descends to near or below sea-level, the seaward side usually being masked by dunes, calcified sands containing land shells or a firm crust of rough-weathering secondary limestone.

Being porous, the limestones have produced rolling, upland country with a red clayey soil in the east, and dry karst-land in the west. Along the larger rivers, however, they make fairly continuous scarps, *e.g.* bordering the Bushmans, Sundays and Zwartkops (Fig. 54). The top of the formation rises to about 1300 feet in the hills south of Sandflats and north of Zuney, to 950 feet south of Riversdale and to 500-700 feet farther west. The maximum thickness must well exceed 500 feet, since 510 feet—including some surface sand—were proved in a borehole on Rietvlei near the coast south of Albertinia.

(*b*) The uniformity of the deposits, areally and vertically, is remarkable. Hard white and creamy limestones, weathering greyish, predominate with sandy or chalky types as well. Certain bands are rich in shells, particularly large oysters, though these are generally broken. They are composed of a mixture of minute shell fragments with grains of quartz sand in varying proportions. Recrystallisation has rendered the boundaries of the shell fragments indistinct and produced a compact rock, often full of small

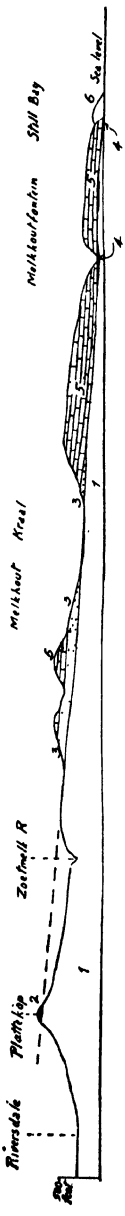


FIG. 66.—Section from Riversdale to Still Bay, distance 22 miles. 1, Bokkeveld Slates; 2, Red Gravel and Surface Quartzite; 3, Red Sand; 4, Conglomerate; 5, Limestone; 6, Recent Sand dunes. (*After* Wybergh.)

cavities. In thin sections tests of *Globigerina* and grains of glauconite have been observed. The proportion of calcium carbonate may be high, but that of magnesium carbonate is always low.

A conglomeratic zone, carrying broken shells in places, is common at the base with well worn pebbles of hard rocks, while pebbly, gritty or sandy layers may occur higher up as well. The massive, basal part was called the " Bathurst Limestone " by Atherstone because the town of that name stands on it. Along the Bushmans River south of Sidbury the rock contains quantities of agates derived from the volcanics of the Zuurberg.

In Riversdale district between Melkhout Kraal and the Zoetmelks River the sporadic basal conglomerate with shells is overlain by soft reddish brown ferruginous sandstones up to 100 feet thick capped by the main limestones. This sandstone zone, which is traceable to the west, thins out to the south. At Windhoek on the Zout River in Bredasdorp a red stratified conglomerate zone up to 100 feet thick and resting on Bokkeveld slates is full of slate débris and angular vein-quartz, whereas the succeeding limestones are free from slate fragments but include worn pebbles of quartz and white quartzite as well as shells.

(*c*) In good sections the stratification is clear with general faint seaward dip, but a strong irregular diagonal bedding is characteristic, at remarkably high angles sometimes, and indicative apparently of wind-action. The limestones must represent inshore deposits that just kept pace with subsidence of the floor. Suggesting the beginning of the transition from the marine facies in the south to the terrestrial in the north there is the wedge of red sandstones in Riversdale, hinting in turn at a possible correlation with the Knysna beds (p. 456).

At the upper quarry at Needs Camp—2 miles west of the lower one (p. 408)—at an altitude of 1205 feet a creamy crystalline limestone is being extracted containing casts of a large " *Perna* "—regarded by Newton as identical with the form *Melina* from the Alexandria Formation—and also sharks' teeth. The chief area lies between Alexandria and Uitenhage, interrupted by the Sundays and Coega rivers (Fig. 54), but much of the lower ground is occupied by Quaternary limestones. Similar beds with *Ostrea* crop out east of the Gamtoos mouth,[1] and begin again west of Mossel Bay.[2] South of the Potteberg and again

[1] F. L. Amm, *T.G.S.S.A.*, 1935, xxvii, 69; S. H. Haughton, *Union S.A.G.S.*, 937, Expln. Sheet 151.

[2] S. H. Haughton, etc., *ibid.*, 1937, Expln. Sheet 201.

between Quoin Point and Stanford the limestones abut against ridges of Table Mountain Sandstone that must have formed headlands during Tertiary times. At Hoedjes Bay and at Langebaan in Saldanha Bay similar limestones built of triturated shells with some quartz sand form cliffs, their granite basement descending below tide-level in places. At one spot on Hoedjes Point a lenticular deposit occurs along the contact, full of boulders and mussel shells, the latter showing gradation into a brown resinous phosphate rock.

(*d*) **Fossils and Age.**[1]—Despite the fossiliferous nature of the limestones, the fragmentary state of their contents has hindered palæontological work, but little collecting has been done. Large examples of *Ostrea*, *Cardium* and *Glycymeris* (the so-called *Pectunculus*) are common along with sharks' teeth. From the basal beds at Birbury near Bathurst at about 670 feet altitude Chapman[2] has identified among other foraminifera *Discocyclina pratti* (Mich.) and *D. elegans* (Kauf.), characteristic of the Upper Eocene, while from Bathurst at about 750 feet Haughton[3] has described sharks' teeth referred to *Carcharodon megalodon*, *C. auriculatus*, *Odontaspis elegans*, *Isurus hastalis* and *I. sillimani*, species known from Eocene beds, and Cox a large *Aturoidea*. From lower positions and younger stages Newton[4] has described the following from specimens gathered at Redhouse, Zwartkops River, Coega River, Coerney and Bushmans River :—

Lamellibranchs—
Cardium edgari Newt.
Chamelea rogersi Newt.
„ *schwarzi* Newt.
Glycymeris pilosa Linn.
Macoma orbicularis Sow.
Melina cf. *gaudichaudi* d'Orb.
Ostrea atherstonei Newt.
„ *redhousiensis* Newt.
Schizodesma spengleri Linn.
Tellina cf. *perna* Spengl.

Lamellibranchs (*continued*)—
Tivela baini Newt.
Ventricola verrucosa Linn.

Gasteropods—
Bullia annulata Lam.
Melapium patersonæ Newt.
Pirenella stowi Newt.
Voluta africana Reeve.

Echinoid—
Archaster patersoni Spencer.

This fauna is allied to the *Miocene-Pliocene* of Europe—both of the north Atlantic and the Mediterranean—and also to that of South America. From near Bredasdorp have come large Ostreas and a large "*Pectunculus*."

The Alexandria Formation includes apparently deposits ranging in age from *late Eocene to Miocene* at least.

[1] See review by E. D. Mountain, *Union S.A.G.S.*, 1946, Expln. Sheet 136.
[2] F. Chapman, *Ann. S.A. Mus.*, 1930, xxviii, 291.
[3] S. H. Haughton, *T.G.S.S.A.*, 1925, xxviii, 27.
[4] R. B. Newton, *Rec. Alb. Mus.*, 1913, ii, 315; W. K. Spencer, *ibid.*, 1915, iii, 65.

(*e*) **Relations of the Alexandria Formation.**—The erosion surface beneath the limestones is now known to lie at a lower level than the higher and earlier of the silcreted surfaces in the districts of Grahamstown, Mossel Bay and Bredasdorp, a relation that may prove general; indeed at certain spots the basal conglomerates carry pebbles of silcrete, as near the Nisbet beacon, Peddie. Mountain [1] has drawn attention to the close agreement between the later or Coastal Plain Silcrete and the pre-Alexandria surface just south of Grahamstown. In the Bredasdorp district not only does the base of the limestone—which contains no silcrete pebbles—lie beneath the nearby cappings of the Lower Silcretes, but the 700-foot peneplane made by the latter will, when prolonged seawards, accord with the crests of the limestones (Fig. 66), being thus not out of agreement with the evidence from Grahamstown. The base is moreover lower than the corresponding—in places silcreted—benches cut in the Table Mountain Sandstone ranges where nearest, such as the Potteberg and Bredasdorp Mountain.

The most reasonable interpretation is that the silicification of the materials on the peneplane was later than the Alexandria Formation, but that the limestone surface experienced calcification instead.

E. Raised Beaches and High Strand-lines

Conspicuous at many places along the coast of South Africa and cut into the sloping land behind the shore are more or less extensive shelves, upon which rest at intervals rolled pebbles, sand and occasionally shells or shelly limestones or phosphatised rocks with perhaps caves to mark former sea-cliffs, as between Gordons Bay and Cape Hangklip or east of Plettenberg Bay. Seldom, however, have the original beach deposits been preserved at altitudes of more than about 150 feet above sea-level, an instance being at Durban, where a patch occurs beneath the red sand of the Berea at 415 feet containing shells, all of living forms. Rarely too are they well dated, an exception being the unique thin group of dark marine sandy shales that crops out from Port Durnford northwards in Zululand [2] with oysters, fishes and foraminifera, having mammalian bones at the base, and overlain by lignites with the dicotyledonous "water-boom," *Eugenia* (Warren), and those by yellow-brown and white false-bedded

[1] *Union S.A.G.S.*, 1946, Expln. Sheet 136, 33; *P.G.S.S.A.*, 1946, xlviii, p. xxxiv.

[2] W. Anderson, *Third Rep. Geol. Surv. Natal*, 1907, 121; W. B. Scott, *ibid.*, 251.

PLATE XLI

[Face page 440

Aerial view looking north-westwards from the Knysna Heads, showing the Harbour, excavated in Cretaceous rocks, the Coastal Peneplain behind, cut across folded Cape strata, and the Outeniqua Range in the background.

sands. The remains include an extinct elephant, *Palæoloxodon zulu* (Scott) and a buffalo, *Bubalus andersoni* Scott, both known from the Younger Vaal River Gravels and indicative of the late Middle Pleistocene.

Because of its mode of development the shelf or bench slopes seawards from *its original inner edge* at former high-tide level. All too frequently the height reported is that of the outer or abrasion-platform, and is far too low, a practice responsible for some of the difficulties experienced in correlating such benches. A good example is that at Hermanus that slopes from 90 to 50 feet—at the water's edge—in 1800 feet. Incidentally, it is cut into the Alexandria limestones near Quoin Point and near Bredasdorp, where it expands to over 10 miles, and into Table Mountain sandstone at Schoenmakers and Humewood near Port Elizabeth. Its presumed extension up the west coast is indicated by relics characterised by *Ostræa prismatica, Thais præcingulata, Chamelea krigei, Donax rogersi* and other forms not living in these waters, *e.g.* at Doorn Baai, the Point, and the Cliffs and Alexander Bay [1] —where it carries diamonds. Its varying height, 35-110 feet, suggests slight subsequent warping of the continent.

This chain of beaches with a full height of about 60-90 feet represents what Krige [2] has termed the "*Major Emergence.*" Accepting the glacio-eustatic hypothesis for the observed world-wide oscillations of sea-level—which the South African evidence strongly supports—this should correspond with the Main Monastirian Level of Europe, that is to say with the Last Interglacial Period, and therefore be of *Early Upper Pleistocene Age* (Table, p. 464). Shells occur on it at Langebaan Road Station at 120 feet, with phosphatic deposits nearby (p. 537). A good example is that south of the Olifants River shown in Fig. 67.

Persistent around Southern Africa, as detailed by Krige, is the 20-30-feet beach of the "*Minor Emergence*" with numerous sea-caves, for instance in False Bay. The shells are mostly of living forms, though some are today restricted to warmer north-eastern waters. At Conception Bay in South-West Africa a conglomerate full of present-day mollusca reaches ten miles inland.

Still lower ledges standing at 12-15 feet or less, with corresponding caves, are common; for example the deposit about two

[1] S. H. Haughton, *T.G.S.S.A.*, 1932, xxxiv, 19.
[2] A. V. Krige, *Ann. Univ. Stellenbosch*, 1927, v, Sect. A, 1.

miles inland from the mouth of the Klein Brak River of limestone resting on a brown sandy clay, both full of shells, all but two of which are of living forms (Rogers).

The precise relations of the Stone Cultures to the Strand Lines are still far from clear. Rolled Chellean artefacts have been recorded from presumed shore-deposits that stand at 200-250 feet in Natal (van Riet Lowe), 300-400 feet about Stellenbosch and near Mossel Bay (Breuil) and about 400 feet at Plettenberg Bay (Mortelmans), though admittedly not associated with shells. Evidence in regard to the Major Emergence is confusing, for which

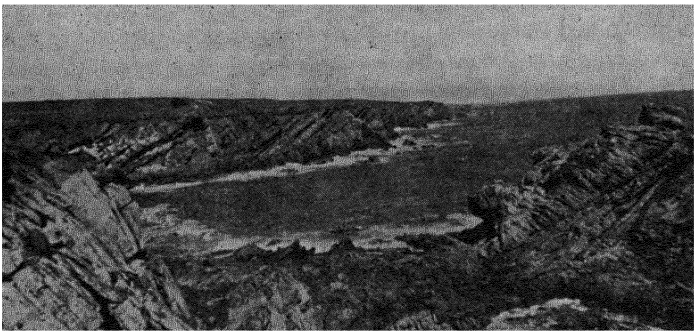


FIG. 67.—Raised Beach materials capping the 60-ft. platform cut in Table Mountain Sandstone at Strandfontein near Olifants River mouth, looking south. (*Photo.* J. Burmester.)

the Table gives some hint. The 20-30-feet beach would, however, seem approximately contemporaneous with Middle Stone Age Man (Goodwin).

F. Drowning of the Coast or Low Strand-lines

Observations made in Europe reveal that the progressively declining High Sea-levels actually alternated with truly Low Sea-levels, the whole constituting a series of marked oceanic oscillations that decreased with time. A great deal, however, of the critical evidence has usually been obscured by the risings of ocean level. Various features point to a final return of the ocean

to a depth of at least 150 feet (25 fathoms), and possibly a great deal more, making it likely that the cutting of that broad and now submerged terrace known as the "*Continental Shelf*" was performed largely while the sea stood at its previous minimum altitude. This applies particularly to South Africa.

(*a*) EVIDENCE FOR DROWNING.—At Paternoster, north of Saldanha Bay, a well sunk at a spot about 20 feet above sea-level revealed the presence of 90 feet of sandy limestone and sand containing land shells, tortoise bones, and broken marine shells—evidently an accumulation formed on the land behind the beach, but now far below tide-level. Saldanha Bay itself is a probable example of a "drowned valley," the arms of which have been buried beneath wind-borne sands. At Kikoes Vlei some distance to the south-east a borehole proved the existence of superficial deposits down to a depth of 50 feet below sea-level. Knysna Harbour may have had a similar mode of origin.

The mouths of the majority of the larger rivers from the Sundays to the Tugela at least indicate through their peculiar type of topography a sinking of the land relatively to the ocean. The normal, rapidly falling rocky-bed comes to an end sometimes miles back from the shore and the river then becomes tidal and expands into a lagoon before escaping into the ocean through a gap, bounded very generally by a sandspit on its left side. Borings show that the original rock-channel descends deeper and deeper beneath an infilling of estuarine sands and muds as the shore is approached. For this reason scarcely any of the large bridges on the coastal roads have had their piers founded upon solid rock.

At the Bitou River near George green sands containing many marine shells, including large numbers of *Cryptodon globosus*, which is now comparatively rare in the adjacent sea, were still not bottomed at a depth of 47 feet below the river. At Mackay Bridge on the Sundays River 3 miles from its mouth bed-rock was not reached at minus 112 feet (Ruddock). In the Buffalo River at East London the bed-rock was found to lie in the middle of the estuary, at a depth of 122 feet below water-level, overlain by over 100 feet of clay, sand, and shelly beds. At Port Shepstone the clays and silts were not yet passed through at 140 feet below low-water mark at a point three-fourths of a mile from the mouth of the Umzimkulu River. At Scottsburg borings in the Umpambinyoni River half a mile from its mouth disclosed the maximum depth of the rock to be 108 feet, while on the Umkomaas River at a distance of three miles upstream the rock was reached at 86 feet below tide level. The phenomenon is repeated all along the north coast of Natal, but rarely has the infilling been drilled right through, and never right along the shore. At the new Umgeni railway bridge, Durban, the maximum depth was 157 feet.

(*b*) THE CONTINENTAL SHELF AND THE AGULHAS BANK.—The exposure at minimum sea-level or sea-levels of much, if not all, of the Shelf could be anticipated, since its deeper outer margin could be accounted for in part by sedimentation, in part by slight recent down-warping.

While but a few miles wide on the south-east, the Shelf is from 30 to 45 miles broad on the Atlantic side, but forms on the south the extensive triangular Agulhas Bank with its apex 150 miles from the present coast. There is a suggestion of two levels (Krige), more than half its surface being covered by less than 60 fathoms, but beyond the ragged 100-fathom line the ocean floor sinks rapidly. The former channels of the Breër (Breede) and Gouritz rivers are traceable across its surface. Submarine canyons are incidentally known off Saldanha Bay, and have been detected by echo-soundings off the Umtata River mouth and Zululand coast.

Dredgings over the Bank—as well as to the south-west of the Cape Peninsula at between 48 and 560 fathoms—have produced glauconitic sands with brown phosphatic concretions, fish teeth, ear-bones of whales and shells. Among the latter was the Miocene species of *Aturia*, suggesting a deeper-water extension of the Alexandria beds. Cayeux [1] has, on the contrary, reached the remarkable conclusion that they are residues of deposits formed at greater depths than those from which they were recovered. Identical deposits from off California have been similarly explained.[2]

Since the Shelf borders the other continents, that feature must have originated in the main through the withdrawal of water from the sea to form the vast ice-caps that developed during the Pleistocene glacial phases, a fall calculated at not less than between 50 and 55 fathoms; with the melting of this ice the ocean would have drowned the Shelf. Under that hypothesis such maximum regression would have coincided with either the Penultimate—and greatest—or the Last Glaciation of the Northern Hemisphere—or more probably covered both of them, as a double phase. The erosion of the Shelf would then have been accomplished in two stages, one before the Major and one after the Minor Emergence—that is in the late Middle and again in the closing Pleistocene (Table, p. 464), a conclusion in close agreement with study of the Sundays River terraces.[3] That so extreme an event could have taken place at so recent a date must cause surprise were not the evidence so hard to explain otherwise.

After small oscillations the sea-level settled at its present height, the drowned estuaries were silted up and the line of wave attack carried inshore.

[1] L. Cayeux, *Ann. S.A.M.*, 1934, xxxi, 105.
[2] *Bull. Geol. Soc. Amer.*, 1942, liii, 815.
[3] A. Ruddock, *T.R.S.S.A.*, 1947, xxxi, 347.

2. Terrestrial Deposits

The accounts of these deposits—mainly gravels, sands, or clays —will be prefaced by some remarks upon those peculiar calcareous, siliceous, and ferruginous types thereof that play quite an important rôle in South Africa, and that are closely comparable with certain of the post-Cretaceous formations well developed in Western Australia and in Queensland. It ought, however, to be mentioned in advance that, while some of the more extensively distributed kinds are quite probably of Tertiary age, very similar deposits were not only accumulated at a much later date, perhaps in the Pleistocene, but appear to be in process of formation in some places at the present day.

A. Surface Limestone or Calcrete

Over very considerable areas, more particularly over flattish ground, limestone may occur either as nodules in the soil or as a more or less continuous sheet beneath the latter. Formed by the evaporation of ground-water bringing to the surface carbonates derived from the underlying rocks, it tends to be confined to that portion of South Africa having an annual rainfall of less than 25 inches, or roughly all but the eastern third. The material is commonly known as " Surface Limestone " or " Calcareous Tufa," but the bulk may in places consist of sand with only a small amount of carbonate of lime as a cement. For all such types Lamplugh has proposed the wider term " *Calcrete.*"

The calcareous substances collect together in certain spots to form small pellets and irregularly shaped nodular lumps : neighbouring masses coalesce and so form layers. The clayey matter in the soil seems to be pushed aside by the carbonate of lime leaving the large sand grains and pebbles to be enveloped by the latter. The upper surface of the layer gets highly irregular and generally compact, while the deeper portions remain soft and porous, being sometimes quite powdery, as for example in the deposit at the Slurry Cement Works near Mafeking. The thickness may range from a foot or two to well over a hundred feet, but there may be considerable variation in the composition at different depths. The forces developed during the crystallisation from solution of the carbonate of lime—through loss of carbon dioxide by exposure or warmth—are immense, con-

sequently the deposition of carbonate within pores and cracks in the solid formation actually shatters the latter, inclusions thereof being in their turn split into fragments that are then pushed apart by newly introduced carbonate of lime; silicification is also a common feature. In this way have been formed the curious calcareous (and siliceous) breccias so conspicuous within the Kalahari region. Where the limestone has formed upon gravel-terraces, the pebbles may have become cemented into a firm rock strongly resembling a concrete.

The limestone is very apt to develop upon those formations containing limestone, dolomite, or lime silicates, for example on the great limestone and dolomite series, the Dwyka Series, Ecca shales, basic igneous rocks and schists; it is much less frequent on granite or sandstone. In its formation the more soluble and stable magnesium bicarbonate and other compounds tend to be eliminated, so that the limestone directly overlying, or deposited by springs arising in, the dolomite have a much lower content of magnesium carbonate than the parent rock.[1] Immense deposits fringe the Kaap plateau that are quarried near Taungs and west of Sydney on Vaal.

On the other hand, in many of the samples collected by Passarge in the northern Kalahari the cementing material is dolomite, due according to Kalkowsky to the local and secondary action of magnesium-bearing solutions on the tufaceous limestones. The same is the case in the partially silicified types, dolomite being seen as irregular grains in the thin section, but sometimes as small rhombohedra. While the process must have been almost entirely a chemical one, it is likely that in certain cases bacteria have been responsible, for instance in the variety that forms around the edges of many pans in the northern Cape and Kalahari—the Pfannenkalktuff of Passarge—a light, highly porous, chalky type traversed by roughly vertical tubular passages—largely the casts of vegetation—and frequently containing remains of mollusca such as *Succinea*, *Planorbis*, *Physa*, *Viviparus*, *Melania*, etc., and often rich in diatoms.

The dolomite of the western Transvaal and that in the Otavi area in South-West Africa are greatly concealed by tufa, while the same is true of the Kaap Plateau in Griqualand West. Calcareous matter has been deposited on a considerable scale beyond the actual limits of the dolomite either by springs or by rivers taking their rise in that formation, for instance the thick sheet of surface limestone all along the base of the Kaap Escarpment and in the areas around Ventersdorp, Mafe-

[1] G. W. Bond, *Union S.A.G.S.*, 1946, Mem. 41, pp. 11-18.

king, and north-west of the Pilansberg. The Kalahari limestone must underlie an enormous region. It builds the great Urinanib Plateau to the east of Keetmanshoop, while great areas are similarly mantled around the Etosha Pan far to the north. Tufaceous limestones are spread over the plain of the Chengane River in Moçambique Territory. They also veneer the Alexandria limestones in the south.[1]

B. Surface Quartzite or Silcrete

Very striking within the Coastal Belt of the south and west, and again in much of the Kalahari region, are certain quartzitic or highly siliceous rocks making fairly continuous terraces at high levels or else patchily developed on the lower ground. *Two* principal types are represented, which in a very general manner characterise the *Coastal Region* and the *Inland Region* respectively. In the littoral the original sand grains or the pebbles have merely been cemented together, by silica chiefly, whereas in the interior a previously formed calcareous matrix may in addition have been replaced by either chalcedonic or opaline silica.

Such rocks, of rather varying character, have commonly been termed *surface quartzites* or "*chalcedonic quartzites*," neither of them an altogether satisfactory title, since glassy translucent types are also to be found, wherefore the more comprehensive name of "*silcretes*" proposed by Lamplugh. That produced by the cementing of sand would be termed a "silcreted sand."

These materials have attained some importance as *refractories*.

1. The general type in the *Coastal Belt*—including much of the silicified High-level Gravels described in Section D—is a greyish or yellowish fine-grained rock without bedding-planes, tending to break with a smooth conchoidal fracture, having an even matrix of chalcedonic silica enclosing angular chips or rounded grains of quartz and other minerals and containing many small irregularly shaped cavities sometimes lined with chalcedonic silica or minute crystals of quartz: properties that enable them to be readily distinguished from other quartzites. Secondary enlargement of the grains is frequent with the interlocking of the crystals so formed, making the rock very intractable. At Grahamstown the grains of detrital quartz and the heavy mineral residues

[1] It is impossible to detail the distribution of the surface limestones; reference should be made to W. Wybergh, *Limestone Resources of the Union, G.S.S.A.*, Mem. II, i and ii; Passarge, *Die Kalahari*, etc.

show a close relation to those of the rock underfoot from which the silcrete has been derived through replacement of the clayey binder by colloidal (chalcedonic) silica (Fig. 68).[1] They are usually underlain by sandy clay or gravel into which they may grade. By an increase in the amount of ferruginous colouring matter they may grade into lateritic ironstones. At The Point on the Van Rhynsdorp coast such may in turn pass into coarse conglomerates containing the shells of living species of marine

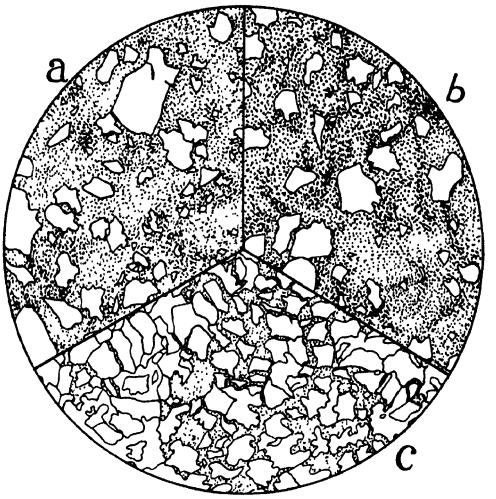


FIG. 68.—Thin sections of Silcretes from near Grahamstown overlying :—(*a*) Dwyka Tillite; (*b*) Bokkeveld Shale; (*c*) Witteberg Quartzite. ×25. (*After* Frankel and Kent.)

forms—raised beaches that lie from 50 to 100 feet above high-water mark.

Such surface quartzites have been developed in the soil in irregular masses or project through it in rounded and somewhat polished surfaces and are most erratic in their thickness and development. At Kliphuis near the mouth of the Olifants River a thickness of at least 30 feet is attained, though such a value is exceptional. Outcrops can be found on the Cape Flats near Cape-town, at many places in the Malmesbury, Piquetberg, Clanwilliam, and Van Rhynsdorp districts, also farther north, as the " Pomona Quartzite " (p. 435).

[1] J. J. Frankel and L. E. Kent, *T.G.S.S.A.*, 1937, xl, 1.

2. The *Inland* occurrences are to be found along the Okavango River, in the neighbourhood of the Victoria Falls and thence towards Bulawayo—usually at the base of the Kalahari Sand—at numerous places in the northern Kalahari such as the Ngami, Ghanzi, Makarikari, etc., districts, and to the south along the valleys of the Upper Molopo, Setlagoli, Kgogole, and Mashowing in Bechuanaland. Varying from white through grey, yellow, brown, red, violet to green in colour, they possess a vitreous lustre, show mottling, and are full of irregular cavities or are traversed by tubular patches of soft sandstone, wherefore they are much pitted at outcrops. They contain grains of quartz, feldspar, etc., in a matrix of chalcedonic silica, and may by the inclusion of pieces of foreign rocks or of another type of calcrete or silcrete pass into *breccias*; layers or veins of translucent grey or yellow opaline silica (silica "gel") are not infrequent. They furthermore pass into lateritic ironstone on the one hand and surface limestone on the other. Now and again they contain small freshwater shells (p. 460).

In particular instances it can be shown that these types have arisen by the replacement of part or the whole of the carbonate of lime by silica, during which process the carbonate left has tended to collect in the form of rhombohedral crystals, chiefly of dolomite, but sometimes of calcite. The unique type of silica, tridymite, has been identified in "opalised" sandstone by Macgregor,[1] while Passarge records a closely similar mineral from specimens of surface quartzite collected on the south side of Lake Ngami and from the Makarikari. A rather remarkable variety is a bright green quartzite found on the floor of a pan at Heuning Vlei north of Kuruman and at Waterpan north-west of Vryburg, on the south side of Lake Ngami, etc. At Waterpan the rock carries quartz, fresh feldspar, zircon, magnetite, and chert in a chalcedonic matrix. The chalcedonic quartzites are so frequently exposed on the floors of the pans in the northern Kalahari that Passarge has indeed termed them the "Pan Sandstone"; they are often dark green.

3. The *explanation* of this very extensive silicification leading to the production of the silcretes, but more particularly the peculiar distribution of the products in this country, is by no means easy.[2] A requisite may have been a pre-existing layer of sandy soil—since removed. As regards those of the coastal belt Rogers has remarked

[1] *Proc. Rhod. Sci. Assoc.*, 1914, xiii, 49.

[2] See A. W. Rogers, *T.R.S.S.A.*, 1936, xxiv, 57; M. Storz, *Die Diamantenwüste Südwest-Afrikas*, 1926, ii, chap. xxv; J. J. Frankel and L. E. Kent, *loc. cit.*; E. D. Mountain, *P.G.S.S.A.*, 1946, xlviii, p. xxx.

that, although the rainfall over the area concerned ranges from almost zero up to almost 30 inches, dews are prevalent. The presence of sodium salts as a possible contributing cause should not, however, be overlooked, for deposition of opaline silica is indeed still taking place on saline muds at Little Brak River, near Mossel Bay. Passarge, on the other hand, says that the favouring conditions are an arid climate in a region of internal drainage followed by a period of greater rainfall; during the dry time alkaline carbonates and soluble silica accumulate in the ground; under wetter conditions the silica is dissolved and replaces limestone and is deposited as a cement between the sand grains. This would apply to the interior region, wherein from the fact that thin films of opal lie outside chalcedony, lining cracks and small cavities in the limestone, it is probable that this process is still taking place. Kalkowsky again is inclined to regard the silica as having been obtained from the siliceous remains of diatoms, such as occur abundantly in the limestones around some of the pans. The abundance of diatoms in the bed and banks of the Nata River and the absence according to Rogers (verbal) of diatoms from the floor of the Makarikari, into which that river discharges, suggest that the silcrete on the pan-floor might have been derived from the solution of such diatoms. Siliceous skeletons of plants, especially grasses—" phytolithariens "—may have been responsible for much silica, especially following fires, when the potash produced would have dissolved such delicate structures. It is improbable that much of the silica could have been derived from the underlying rocks, for to the north-west of Bulawayo the silicification at the base of the Kalahari Sand is quite as marked even where the foundation consists of basalt.

C. Lateritic Ironstone or Ferricrete

In many parts of South Africa a peculiar ferruginous material can be observed resting either directly upon the decomposed underlying rocks or more usually with the intervention of sandy clays. It is called by the farmers " ouklip " and is believed by many of them to represent a lava flow of great antiquity, although usually the youngest formation present. It may vary in its nature very greatly within short distances, but is a rather slaggy or lumpy-looking rock at the outcrop, generally cellular with the hollows lined with red, brown, or yellow ferruginous material, while below it becomes softer and less ferruginous. Transitions can be found from ferruginous pellets scattered through the soil, through loosely aggregated streaks and lenses, to compact ferruginous beds ranging up to several feet in thickness, occasionally more.

Most commonly there is a large proportion of clay, sand, and angular fragments of quartz or other resistant material, cemented together by hydrated oxides of iron, but in places the rock may be a nearly pure limonite or "pisolitic ironstone" such as could be used as an iron ore. It usually appears as a rough surface crust or as a layer beneath a thin covering of sandy soil and tends to form principally on flat or gently inclined surfaces; on even moderate slopes it is only poorly developed or consists of subsoil or rubble cemented by ferruginous matter.

Though these ferruginous rocks have almost universally been termed *laterites*, it would be preferable as well as more accurate to call them *lateritic* or *lateritoid rocks*.[1] In the true laterites the breaking up of the silicates of the underlying formations has led to the removal of the silica, alkalies, and alkaline earths, leaving hydrated oxides of iron and aluminium principally; in the latter types the silica has been set free or left combined with the alumina as silicate and is accompanied by a variable amount of hydrated oxide of iron. Laterite proper, with hydrated alumina predominant, is as yet only known extensively in north-eastern Rhodesia and Nyasaland, where important *bauxite* bodies cap the syenite of the Mlanje Mountains. Bauxite is being mined north of Umtali just inside Portuguese Territory.[2]

The deposits represented in South Africa are distinctly low in this compound and are for convenience roughly divisible into two classes, the *siliceous laterites* and the *lateritic loams*, according to the amount of free quartz, etc. Lamplugh has named them all "*ferricretes*." Like the true laterites, however, they possess the peculiar property of hardening with exposure, this being connected partly with the presence of colloidal substances and partly no doubt with the influence of bacteria. A binding character is thus conferred, which is particularly valuable when the material is used for road-metal. From their composition and mode of origin this material is very poor agriculturally. A feature of these lateritic rocks is that they have been derived from formations of the most diverse character, such as granites, sandstones, slates, basic schists, basalts, etc.

In the Western Province such deposits are common both on the Malmesbury slates and on the granite, especially on the gently rising

[1] For a useful summary of the controversy upon the origin of laterite, see L. L. Fermor, *Geol. Mag.*, 1911, 454, etc.

[2] *Min. Jnl.*, 1941, 52, pt. i, 739, 741.

ground, while more to the east they constitute much of the materials building the high-level Tertiary terraces, as will be detailed later; in these they are intimately associated with highly quartzitic rocks (surface quartzites). Over wide areas in the southern Transvaal and the northern parts of the Orange Free State and Natal the Ecca Coal Measures make few outcrops because a thick layer of siliceous laterite intervenes between the sandy soil and the weathered beds. Indeed, so universal is this that such laterite is largely an indication of the presence underfoot of Karroo sediments. In the Middelburg district beds of limonite rather high in iron have been so formed. Some of the iron has doubtless been furnished by the oxidation of concretionary pyrite. In Southern Rhodesia lateritic ironstone has a wide distribution, mainly upon the granites and schistose rocks, while it is well developed beneath the Kalahari Sand both in the north-west and in the outliers in the centre, such as that at Gwelo. In South-West Africa it does not appear to be common, but has been recorded in the neighbourhood of Karibib.

Origin.—These curious deposits have been formed by the concentration within the surface layers or subsoil of hydrated iron oxide derived from the decomposing rock beneath, but also in sandy soils that have been brought into their present position by water or wind.

When humous substances are taken into solution by ground-water, some of the humic acids react on the mineral matter present to form soluble humates, including those of iron, which furnish food for micro-organisms, the latter incidentally stimulating rock-decay. Such is probably the usual process in sour soils. Iron bacteria,[1] for example *Spirophyllum*, *Leptothrix*, and *Cladothrix* are each able to separate ferric hydrate from extremely dilute solutions under some special set of circumstances, and remains of such organisms have been detected in some of the South African deposits. Various impurities are also precipitated, such as silica—mainly in the colloidal form—oxides of aluminium and manganese and certain phosphates. Indeed, manganiferous varieties, recalling those of India, have been developed in a few places, *e.g.* on gravels at Somabula in Rhodesia and on the dolomite at Krugersdorp and elsewhere in the Transvaal. In the presence of any appreciable amount of lime, however, lateritoid rocks do not appear to form.

Factors favouring their formation would appear to have been :—(*a*) a flattish surface not subject to erosion ; (*b*) an acid sandy top-soil ; (*c*) a moderate to high rainfall ; (*d*) according to Mennell and some

[1] E. C. Harder, *Iron Depositing Bacteria*, U.S. Geol. Surv. Prof. Paper, 1919, 113.

other geologists, a contrasted wet and dry season. Such is true of most of South Africa, though the material is equally represented in George and Knysna, a region with an evenly distributed rainfall. As regards their age, Van Riet Lowe and Cooke have made the pointed observation that in the Union Middle Stone Age tools tend to occur in or be enveloped by ferricrete. Lateritization is, however, still active to-day.

D. The " High-Level Gravels " and their associated Terraces

1. Between the shore and the Main Escarpment—well developed in the south and south-east—are relics of former *erosion-surfaces* that become fainter and more fragmentary with height, yet may be traceable for long distances (Plate XLI). Certain indeed stand at 2000 feet or more, although in sight of the ocean. Of such can be cited the Inland and Coastal Plateaux of Natal, the Coastal Terraces of Pondoland,[1] falling in steps to the sea, or the benches of Bredasdorp, the complex histories of which have still to be worked out.

These features are difficult to interpret save as having been evolved when the land stood far lower in relation to the sea. Whether they were wholly or partly wave-cut has given rise to much discussion,[2] but that they were ocean-controlled in an intimate sense cannot be doubted. The highest benches, although intriguing, are too speculative for discussion.

2. Prominent among them, from False Bay to East London, are those which, although greatly dissected, have retained in surprising degree their plain-like characters through the consolidation of their original coverings of gravels and sands because of peculiar climatic conditions during, or shortly after, their aggradation. To-day they are conspicuous as terraces or scalloped fringes (" epaulettes ") along the mountains, while represented away from the latter by more or less table-topped hills with sharp edges, and ultimately by pinnacles, all reaching to about the same height. They slope gently towards the coast, or, if situated between mountain chains, towards the axis of the valley, and are cut equally across the harder folded Cape beds and the softer Uitenhage strata.

[1] A. O. Thompson, *T.G.S.S.A.*, 1943, xlv, 37.

[2] E. H. L. Schwarz, *Q.J.G.S.*, 1906, lxii, 70; *G.J.*, March 1906; *Am. J.S.*, 1907, xxiv, 186.

Conveniently known as the HIGH-LEVEL GRAVELS, these deposits are generally coarse, though variable, ranging from loose boulder-strewn slopes and pebble-beds to intensely hard conglomerates in which the rock breaks across matrix and inclusions alike. Near the mountains the materials are much coarser, subangular boulders several feet across being found; farther away they pass into conglomerates with well-rounded pebbles, and beyond into finer-grained highly ferruginous or siliceous rocks, which may contain angular pieces of vein-quartz from the Bokkeveld slates or Witteberg beds that usually underlie them. The finest grained kinds are brown, yellowish, or greyish silcretes of typical character, often directly underlain by white or yellowish clays bleached by the removal of the iron which they once contained and which has either been abstracted or concentrated into the overlying rock. Sometimes these clays have arisen by the weathering of slates *in situ*, but more generally they seem to have been transported to their present position. In the Riversdale districts valuable deposits of ochres have been formed from Bokkeveld slates in such positions.[1] The crumbling away of these softer beds leads to the strewing of the hillsides with large irregular blocks of silcrete. In the Sugar Loaf Hill and in the terrace to the north of it a couple of miles outside Grahamstown, the rock is about 20 feet thick, passing down without a break into clays that are as much as 40 feet thick in places. The top of the conspicuous Kentani Hill east of the Kei River displays an almost identical section. Silcrete pebbles in solid silcrete have been observed at Grahamstown and Albertinia (Kent).

3. *Extent and Altitude.*—There would seem to have been at least *two* successive stages of planation, deposition and cementation that produced surfaces differing by a few hundreds of feet in height, but separated apparently by an appreciable interval in time. The otherwise well-defined Coastal Platform is therefore composite, and has furthermore been modified by still younger benches obviously related to the existing drainages.[2]

The more persistent is the *Lower Peneplain*, standing at 700 to 800 feet, beginning in the west at Hermanus, extending through Bredasdorp, Mossel Bay, George and Knysna (Plate XLI), repeated beyond in Humansdorp and between the Gamtoos and

[1] *Union S.A.G.S.*, 1937, Bull. 9.

[2] For the latest discussions, see F. Dixey, *T.G.S.S.A.*, 1943, xlv, 151.

Port Elizabeth. Beneath this surface the Breede, Gouritz, and other rivers have entrenched themselves. East of Alexandria it rises inland to 1000 to 1500 feet with numerous silcrete residuals.

The *Higher Peneplain*, standing at 1000 to 1250 feet, begins in the west at False Bay, its remnants dotting the " Ruens " (Ruggens) between Caledon and Heidelberg, to reappear in the east at Bellevue, 1600 feet, and at Grahamstown, 2050 to 2200 feet, where it is strongly silcreted.

Inland this terrace rises steadily near Uitenhage to 2600 feet, bordering the Great Winterhoek and Zuurberg Ranges,[1] and west of Humansdorp up the Long Kloof and Baviaans Kloof to about 3000 feet at the divides with the Olifants and its tributaries. The terraces are finely developed about Toverwater Poort, Strydberg, etc., where they stand at a maximum height of about 900 feet above the Olifants channel (Fig. 58). Between Oudtshoorn and Uniondale the Kamanassie River flows for miles in a trench cut 800 to 1000 feet deep in this surface. Corresponding benches are found to the west in the Ladismith district.

Within the next barrier, formed by the Swartebergen and Wittebergen, remnants of the surface can still be found at altitudes ranging between 2000 and 3000 feet above sea-level along the northern base of the Wittebergen, the terraces being not only conspicuous but arduous to traverse on foot because of their boulder-strewn nature; the materials show only slight consolidation.

4. *Age of the Coastal Peneplains.*—The only fossils from the deposits are stems and roots of *Podocarpus* and *Widdringtonia* in silcrete from Fort Grey near East London,[2] and the reports, as yet unconfirmed, of *Chara* and *Limnæa* from near Komgha. The sole age-indication throughout this lengthy stretch rests on the relation of the silcretes to the Alexandria beds and even that is not precise.

The Earlier or Grahamstown Silcrete must be post-Lower Cretaceous but pre-Upper Eocene—say *Early Tertiary*—the Later Silcrete, if one can accept the slender evidence from Bredasdorp, post-Miocene—say *Late Tertiary*. Until these various surfaces have been systematically mapped for long distances,

[1] S. H. Haughton, *T.G.S.S.A.*, 1925, xxviii, 27.
[2] R. S. Adamson, *Ann. S.A.M.*, 1934, xxxi, 67.

their correlation and dating must remain uncertain, preliminary work having disclosed the complexity of that problem.

E. The Knysna Beds [1]

In the forest-clad area to the east of the town of Knysna certain deposits of sand, perhaps a full 200 feet in thickness, containing clay and lignite, rest upon a surface cut in the Table Mountain Sandstone, the beds being exposed in railway cuttings, drives into the sides of gullies and in shafts. Usually the sand is strongly false-bedded, red or yellow in the upper parts and brown in the lower owing to organic matter. The lignite occurs in several layers, which in places have a total value of 17 feet. The only fossils are coniferous wood ascribed to *Widdringtonia* and poorly preserved leaves of *Podocarpus*, *Gonioma*, and *Curtisia*,[2] forms living in the neighbourhood, which, taken with the incoherent nature of the formation, suggests a Tertiary age.

The beds are of scientific importance in that they rest on the coastal shelf, here high and dropping gently seawards, their base reaching the 1300-feet contour between Mill Wall and Park Stations. Whether the sea ever covered them is unknown but, since the lignite and associated clays were probably deposited in lagoons, they must have been formed when the continent stood at a much lower level relatively to the ocean. It is just possible that they correspond with the soft sandstones at the base of the Alexandria Formation; they also recall the red coastal sands of Natal and Zululand with pebbles and large well-rounded boulders towards their base, frequently seen at from 200 to 300 feet above sea-level, and those covering a great area in Portuguese East Africa.

Sands, clays, and lignites are known to form an outlier near Mulders Vlei between Cape Town and Paarl resting in a hollow in granite, while a similar deposit has been reported from a point not far from the coast north of the Olifants River in the west, lignite having been discovered in sinking a deep well; it is stated to be quite high in volatile matter.

F. The Deposits of the Kalahari

As mentioned in Chapter II, the solid geology in this vast interior region, fully ten degrees in width, is concealed over all but a trifling proportion by a mantle of superficial deposits, of which the most obvious and extensive is the "Kalahari Sand."

The flat nature of the ground is not conducive to the finding

[1] A. W. Rogers, *Ann. Rep. G.C. for* 1908, 129.

[2] J. F. V. Phillips, *S.A.J.S.*, 1927, xxiv, 189.

of illuminating sections, though some good ones are supplied by the drainage systems marginal to the Kalahari, such as the Okavango, Zambezi, Molopo, and Nossob, copiously supplemented farther away by the numerous pans of the region, which show that beneath the prevailing sand lies a widespread sheet of more consolidated materials, ranging from a soft sandstone to a calcareous, siliceous, or ferruginous rock, borings having proved depths of several hundreds of feet in places. Towards the interior opportunities for examining the base of the deposits become infrequent, the inliers of the older rocks get rather widely spaced, and practically nothing is known concerning the full depth or nature of the lower portions.

Fortunately, boring has been carried out extensively in the south and west, furnishing evidence as to the nature, thickness and variation of those hidden strata and indicating the stratigraphical importance of such accumulations. Over a large proportion of the region the older rocks must first have been worn down considerably, though not to a peneplane, save in certain areas, as can be finely seen between Bulawayo and the Zambezi, or in the edge of the Urinanib Plateau in South-West Africa, wherein beds of gravel or breccias not infrequently mark the base.

To these deposits—*exclusive of the Kalahari Sand*—Passarge [1] gave the name " Botletle Beds " (from the channel of that name east of Lake Ngami) ; but the term " Kalahari Beds " is in general use, though not free from confusion.

1. The Kalahari Beds

(*a*) **Calcareous Rocks.**—In South-West Africa one finds the great Urinanib Plateau (the " White Plain "),[2] a nearly perfect tableland 250 miles in length and up to 50 miles in width, extending from a point well north of Mariental down into Gordonia and then far up the Molopo, a continuous sheet of light calcareous sandstones or grits, becoming richer in lime towards the top and generally exhibiting a hard crust of white limestone, which may be silicified in places. The rock usually encloses small pebbles and passes into coarse calcareous grits and conglomerates with pebbles of granite, gneiss, quartz, and Fish River sandstone.

[1] S. Passarge, *Die Kalahari*, 1904, chap. xxxiv.
[2] P. Range, *T.G.S.S.A.*, 1912, xv, 63.

This calcareous sheet, with an imperceptible fall in a south-easterly direction, passes eastwards beneath the vivid red sand-dunes of the Kalahari to reappear within the trough-like valleys of the Auob, Elephant and Nossob, along which it makes cliffs, or to show in sundry pans in that direction sunk well beneath the general surface of red sand. It seemingly underlies the sandveld over nearly all the southern Kalahari; indeed borings have proved its existence beneath the bed of the lower Kuruman River, in and around the Koranna Berg, about Genesa and in the northern parts of Vryburg and Mafeking.

There can be no doubt that this widespread deposit, with its occasional conglomerates, resting on the most diverse of rock groups, is largely of *fluviatile origin*, though some æolian action is not excluded.

In the Urinanib Escarpment the thickness is from 30 to 60 feet (excluding the dune sands); but boreholes in the upper Auob show over 200 feet and in one case 300 feet, while on the lower Kuruman and on the Molopo just above its junction with the latter the figure of 300 feet is exceeded without an older formation being struck. A few wells disclose a bright yellow or brick-red sandy material, sometimes a stratified and occasionally ochreous sandstone, soft in places, hard in others, along with bands of pale purple shales and clays. The formation possesses importance as the water-carrier in this arid region. Along the Auob to its junction with Nossob and again on the lower Kuruman the water-table is even and the supplies are fresh—up to 25,000 gallons a day being obtained—but down the lower Nossob to its junction with the Molopo and up the latter the water-table undulates and the waters are usually salt or bitter.

Approaching the Koranna Berg and the Langeberg the deposits conceal a plain from which stand up narrow chains of ancient quartzites (Plate XII), and boring has shown that over much of this section the covering exceeds 200 feet, from 300 to 380 feet having been attained sometimes quite close in under these ranges. Much of the sandy stuff has been partly and erratically compacted by a calcareous or siliceous cement, but the calcareous zone so typical of the area to the west is thin or absent in the neighbourhood of the mountains, though well developed to the north-east along the Gamagara valley.

(*b*) **Sandstones and Marls.**—About Kudumalapshwe, north-west of Molepolole, yellowish shaly beds with fibrous limestone bands crop out, followed by a massive red to maroon sandstone with opaline druses, and that by paler sandstones, all dipping faintly northwards, proved by boring to exceed 200 feet thick. Their age is unknown.

Beneath the sand, sandstone and limestone a group has been found in the south-eastern corner of this region composed of pink or red calcareous clays. Only rarely exposed beneath bluffs of limestone and chalcedonic quartzite along the Upper Molopo and its tributaries,[1] the marls have been shown by borings to extend well away from the present valleys and to have a wide distribution from the Koranna Berg eastwards to Pitsani and northwards to the Bechuanaland border. They either rest directly upon the old rocks or are themselves underlain by the sands and soft conglomerates that constitute the base of the Kalahari beds in this quarter.

They are peculiar in being extremely fine-grained, although gritty through carrying scattered grains of quartz, are homogeneous and exhibit no stratification. Under the microscope one sees an abundance of minute elongated crystal aggregates of calcite shaped very much like grains of rice, small particles of quartz and indeterminate pinkish clayey matter. In addition to grains of heavy minerals such as cyanite and garnet minute crystals of barite may be present.[2] No diatoms have been detected for certain, nor other fossils. In certain places the marls pass downwards into a white powdery material composed almost wholly of granules of calcite, a type which was fully 30 feet thick on the farms Matlock and Albury, east and north-east of Morokwen, overlain in the latter case by 125 feet of pink marls. Many of the boreholes have had to be stopped in this rather waterless formation, so that the maximum thickness is rarely known. Over 50 feet is not uncommon, while the exceptional value of 166 feet was found on the farm Arcadia in the north of the Koranna Berg, the base not having been reached.

In the cases quoted the marl division is a single bed, but beneath the Gamagara flats it is split up by one or more bands of hard sandstone or quartzite (silcrete), while in the area due west of Genesa and again well to the north thereof the marls pass either downwards into yellow or red conglomeratic sandstones or laterally into pot-clays, yellow sands, and gravels.

The entire Kalahari Formation attains a remarkable thickness to the west of Genesa : 307 feet on Curzon, 407 feet on Barden, and the phenomenal figure of 463 feet on Dithlaradintsi, where incidentally it rests on supposed Karroo shales occupying a hollow in the granite. The coarser pebbly basal beds here recall those of the Urinanib and are obviously fluviatile in their nature, but the marls present a peculiar problem. The silcrete or the calcrete that invariably overlie the latter are often pink at their base, but the boundary is generally a sharp one and at one point at least, on the Kuruman River just below Gasese, a sheet of gravel rests on the top of the marl, pointing to the advent of totally different geological conditions.

[1] *Ann. Rep. G.C. for* 1907, 151.

[2] A. W. Rogers, *T.R.S.S.A.*, 1936, xxiv, 57.

(*c*) **Silcretes.**—Details have already been given (pp. 449-450) regarding the types of secondarily consolidated materials so commonly present beneath the sand. Ferricrete (lateritic ironstone) has certainly been developed through cementation from and at the base of the sand in many places. While a similar process was claimed for silcrete by Lamplugh, Passarge's prior conclusion has received confirmation that it is everywhere older than, and lies unconformably beneath, the Kalahari Sand. Where both kinds are present in Rhodesia, the ferricrete overlies the silcrete. The silicification appears to have been more effective close to the surface, for the extreme opaline varieties have rarely been proved in drilling. This would serve to explain the silicification of exposed surfaces of Fish River sandstones near Grootfontein in South-West Africa or of Forest sandstones in the area north of Bulawayo.

The name " Gwampa Chalcedony " was proposed by Macgregor for this silcrete in the Gwampa, Kana, and Shangani valleys from which stems and seeds of the aquatic plant *Chara* and the fresh-water shells—*Viviparus*, *Paludestrina*,[1] and *Isidora* and *Melania*?—have been obtained, thereby paralleling the many and better known occurrences in the Congo and Angola. Comparisons were originally made with similar fossiliferous silcrete from Komgha and Ermelo, but at neither of these places has the material been located *in situ*.[2]

(*d*) **Age.**—The distribution of such a quantity of rock-waste over a region, wherein transport is almost negligible, must have taken a considerable time. The bulk being fluvatile and a part lacustrine, it must have been laid down under conditions very different from those of to-day

The poverty of fossil remains prevents direct proof of age, which can only be arrived at indirectly. Erosion, following uplift, has removed a great mass of Kalahari beds from two sides of the Kalahari. The Loale Plateau to the west of Palapye has been eaten back until the basement " ironstone "—overlain by the red sand—is now standing at over 400 feet above the country to the east.[3] Range has pointed out that the pebbles in the base of the Urinanib Plateau were apparently transported from the north and west, but the Fish River by cutting back has removed the north-westerly extension of the deposits, and at Gibeon is flowing at a depth of over 400 feet beneath the top of the escarpment. Assuming that the surface of the Kaap Plateau originated during the same period, the great trough of the Harts-Vaal-Orange River below Douglas has been cut to a depth of 800 feet.

Discussing the mollusca from Rhodesia, Newton suggested a high

[1] R. B. Newton, *Ann. Mag. Nat. Hist.*, Ser. 9, 1920, v, 241.
[2] L. E. Kent and E. L. Stephens, *T.R.S.S.A.*, 1947, xxxi, 381.
[3] S. Passarge, *Die Kalahari*, 1904, 520.

antiquity, while Passarge favoured an Eocene age.[1] The fossils are, however, unsatisfactory for dating. In the Congo and Northern Rhodesia attempts have been made to date such remains from the associated erosion-surfaces, but the results are inconsistent. Dixey[2] has favoured a late Tertiary age for the beds and their silicification. Because of the overlying Kalahari Sand a *pre-Pleistocene age* is alone assured.

[*Editor's Note.*—In a recent paper (*Mém. Soc. Belge de Géol.*, 1952, iv, 7) L. Cahen and J. Lepersonne have divided the Kalahari beds into three series. The lowest or Kamina series of sands, sandstones and gravels is truncated by an upper Cretaceous land-surface (equivalent to the " Gondwana " surface of L. C. King) ; the Middle series of sands, silicified sandstones and chalcedonic limestones (grès polymorphes or Botletle beds) rests upon this surface and is terminated by a mid-Tertiary surface (King's " African " surface) ; the Upper series of ochreous sands has its upper limits at the end-Tertiary surface. Posterior to the cutting of this surface were formed Recent sands including the implementiferous Carstone rubble and Red sands of the Victoria Falls area. The term Mont Bunza formation is considered to be equivalent to Kalahari beds.]

2. The Kalahari Sand

(a) Beginning at the Orange River at Kheis, spreading over the Kalahari and adjoining parts of South-West Africa and Southern Rhodesia and thence far into Angola and Northern Rhodesia, extends this almost uninterrupted mantle of transported red to grey sand resting unconformably on a surface, partly of evenly spread Kalahari beds, partly of eroded older rocks, flattish in some sections but uneven in others. Over long stretches its boundary has been defined through erosion and is sharp ; elsewhere it fades out or merges with rather similar sands developed from the underlying rocks. That it had a still wider extension formerly is proved by outliers, particularly on the east, such as those around Bulawayo, Gwelo and Umvuma, as well as the north-west of the Transvaal and Orange Free State. A former junction with the coastal sands of the Namib on the west and those of Moçambique on the east is indeed probable. In the south-west its surface has been thrown into innumerable " seif " dunes trending north-west to south-east, which fade out eastwards

[1] *Ibid.*, chap. xxxvi.
[2] F. Dixey, *T.G.S.S.A.*, 1942, xliv, 39.

into gentle undulations, the whole country being grassed and carrying a fair amount of shrubs or timber, particularly in the north-east. A thickness of from 40 to 50 feet of sand is common, while 200 feet is exceeded in the Gwaai Reserve, but over most of the region the depth remains unknown.

Rarely do the basement rocks project, and then mostly between Windhoek and Wankie, though exposed along the incised channels of the Zambezi, Gwaai, Molopo, Nossob and Kuruman rivers.

The sand varies in tint from deep red—especially in the south and west—through pinkish and yellowish to pale grey, the last-named generally over well-wooded ground or in depressions such as the Okavango swamps. The red colour is due to iron oxide forming a skin or filling microscopic cracks in the quartz grains. Considering the vastness of the region, the fineness and uniformity in texture are remarkable, the grain-size rarely exceeding 1 mm. and ranging most commonly between 0·15 and 0·4 mm. with the particles not very well rounded or sorted. Coarser particles can usually be traced to inliers of siliceous rocks. The heavy minerals include ilmenite, magnetite and metamorphic species, while some diatoms are normally present.[1]

The sand rests with a break even upon the Kalahari beds, as shown by the absence of pebbles in its base where the sand overlies the calcareous grits of the Nossob, the silicified gravels north-west of Molepolole, the silcretes at the Victoria Falls and elsewhere, while in the Ghanzi district the writer found conglomerates beneath the sand carrying pebbles of silcrete and calcrete. The erosion-break at the Falls, reported by Maufe and confirmed by Dixey and Cooke,[2] may well prove universal.

(b) *Origin.*—That this vast covering must have been scattered by the wind under conditions of widespread aridity has never been doubted, though the causes therefor as well as the precise sources of the sand remain obscure. The writer fancies that it was largely blown in by strong south-westerly winds from the coast of South-West Africa, where enormous dunes are still being formed. Comparison can incidentally be made with the dark red to chocolate sands—in which glauconite grains have been found (Kent)—forming a narrow belt along the coast of Natal and Zululand with great expansion in Portuguese Territory.

[1] A. W. Rogers, *T.R.S.S.A.*, 1936, xxiv, 57.

[2] H. B. Maufe, *S.A. Geogr. Jnl.*, 1935, xviii, 3; *T.G.S.S.A.*, 1939, xli, 211; H. B. S. Cooke and J. D. Clark, *T.R.S.S.A.*, 1939, xxvii, 287.

(c) *Age.*—Of special importance is its relation to the Human deposits. Although regarded as old by Passarge, there have been found *in situ* underneath the sand at the Victoria Falls artefacts of pre-Chellean type including rostro-carinates (Maufe, Cooke, and Clark). An identical relation has been observed on the Kasai in Angola by Janmart. A similar pebble and flake culture has been got at Windsorton on the Vaal River below red æolian sand. The Kalahari Sand will therefore be for the most part of *Lower or Middle Pleistocene Age.* Because of its wide distribution, the deposit could hardly be of the same date everywhere. At Taungs the presence of the ape skull *Australopithecus* seemingly marks the early stages of this sand-incursion.

G. The " Low-Level Gravels "

Exceptional interest attaches to these deposits of the Inland region, since in certain parts of the Union they have produced alluvial diamonds and, in their younger parts, a rich and varied mammalian fauna, an abundance of artefacts marking various stages of the Palæolithic (Chapter XVIII) and have furnished critical evidence concerning climatic environments. Regarding the type area of the Vaal River, first comprehensively dealt with by Söhnge, Visser and Van Riet Lowe,[1] an extensive literature has grown up, well summarised by Cooke,[2] though the problems raised are too wide to be dealt with adequately.

The Oldest Gravels here—rich in boulders of Ventersdorp lavas—standing in places at 300 feet or more, have yielded a stem of *Palmoxylon* at Barkly West. The succeeding Red or " Potato " Gravels are thin but widespread and have given some crude pebble and flake tools. The Younger Gravels, particularly well developed about Windsorton, are divisible into several horizons with associated reddish sands and have furnished from the diggings between Bloemhof and Sydney teeth and bones of numerous species of elephants (*Archidiskodon, Palæoloxodon, Loxodonta*), the ungulate *Griquatherium, Equus capensis, Hippopotamus, Bubalus baini*, carnivores, pigs, etc., many of them extinct, and indicating collectively a *Middle to Upper Pleistocene Age.*[3] The associated cultures are dealt with on p. 470. Comparable deposits and faunas have been recorded from the Victoria Falls.[4] Subdivision of many of these gravels must nevertheless be made through their contained stone implements.

[1] *Union S.A.G.S.*, 1937, Mem. 35.
[2] H. B. S. Cooke, *T.G.S.S.A*, 1947, xlix, 243.
[3] H. B. S. Cooke, *Union S.A.G.S.*, 1941, Mem. 35, pt. iii.
[4] H. B. S. Cooke and J. D. Clark, *T.R.S.S.A.*, 1939, xxvii, 287.

H. Table of Pleistocene Events in South Africa

Periods	Europe	Sea-Levels	Marine	Terrestrial		Fluviatile	S.A. Cultures
Holocene or Recent	Post-Glacial	Present 5′–10′	Lagoon Silts Lowest Beaches and Sea Caves	Tufa, etc. Ferricrete	Kalahari Sand	Alluvium and "Recent Gravels"	"Midden" Wilton Smithfield
Pleistocene — Upper	3, 2, 1 Fourth Glacial Third Interglacial	Low Very Low 20′–30′ 50′–90′	Development of the Continental Shelf Minor Emergence Major Emergence	Coastal and other Cave Deposits Calcrete		Vaal River Gravels: "Youngest"	"Middle Stone Age" Fauresmith
Pleistocene — Middle	2, 1 Third Glacial Second or Great Interglacial	Low High	Zululand Clays	Cave Breccias: Makapan,		Younger	Stellenbosch (Chelles-Acheul)
Pleistocene — Lower	2, 1 Second Glacial First Interglacial First Glacial	Low 150′–200′	Coastal Terraces	Sterkfontein, Kromdraai, and Taungs		Older or Red Basal	Pre-Stellenbosch (Pre-Chelles-Acheul)
Pliocene and Older	Pre-glacial	250′–500′ Low	Alexandria Beds	Silcrete Kalahari Beds		Coastal Gravels High Level Gravels	Pebble-types

I. Pans

A remarkable feature about South Africa is the abundance of those peculiar depressions called "pans," of which two main classes can be made—those near the coast and those inland. A minority are hollows in the bedrock, the majority being sunk in or through superficial materials.

The **coastal pans** are usually at a low level, being frequently lagoons that have been cut off from the sea by a belt of sand-dunes, and are therefore elongated; they are numerous along the Atlantic coast, more particularly from Lüderitz northwards. The majority are saline, evaporating sea-water having furnished the salt, which may form a thick crust as at Cape Cross, while the muds beneath may contain crystals of gypsum as at Port Nolloth. In other cases the drainage from the higher ground—over which salty spray has been blown—collecting in these hollows gives on evaporation a crust of salt. On the Bredasdorp coast, however, salt and freshwater pans occur in close proximity, a fact difficult of explanation. The Bethelsdorp and Zwartkops pans near Port Elizabeth are each sunk in marine Cretaceous clays and limestones. Immense pans, many with permanent water, fresh or salt, characterise the Portuguese littoral, especially in the wide stretch between the Limpopo and Sabi rivers.

The **inland pans** are abundant over a belt of country extending from the north of Calvinia through Britstown and the west of the Free State, with an arm stretching through Gordonia towards Gibeon; this coincides roughly with the outcrop of the Dwyka tillite and shales. They are usually circular or oval—more rarely irregular in outline—and vary from a few yards to many miles in width. Haakschein Vlei and Koppies Kraal Pan in Gordonia are respectively 14 miles by 6 and 9 miles by 5, while the Governments Pan near Strydenberg is 16 miles by 2.

The floors are sometimes red, mostly drab clays, powdery when dry, sometimes impregnated with gypsum, and usually underlain by shales, while the water during the wet season is frequently salt or charged with magnesium compounds (p 551). In the Boshof district a connection has been noted with dolerite dykes, which must formerly have thrown out springs.

Astonishing is the number of pans on the Coal Measures of the Transvaal high-veld, sometimes miles across, and occasionally eroded through to the sub-Karroo foundation. Their floors are

generally made by dark clayey soil and the water is always fresh. Of the group situated on the watershed of the Ermelo district, of which the largest is Lake Chrissie 6 miles across, the majority have faint connected out-flow channels discharging eastwards.[1] Pans are frequent on the Dolomite of the Marico district and on the Kaap Plateau and are generally bordered by calc-tufa. The Kalahari region is characterised by a multitude of "calc-pans,"[2] their floors eroded mostly in a brownish-red silcreted sand—greenish on the pan-floor—called by Passarge the "pan sandstone," while the rims of the hollows are usually made by a thick stratum of very cellular, porous tufa in which fresh-water shells are common; diatomite may occur as well.

Origin.—It can hardly be doubted that wind erosion has largely been responsible for these hollows. Water accumulating periodically in a faint depression would tend to make the rock underfoot weather more rapidly than elsewhere; the clay formed would on drying produce a powdery soil, and this would then be blown out by the wind, the surrounding vegetation preventing the material from being washed back by the rain. Such weathering would be more intense when, as so frequently happens, the waters are saline and incrustations form in the dry season on the pan floor. The southern and south-eastern sides of many pans are bounded by an area of light-coloured sand, sometimes forming dunes, for example Saltlake between Belmont and Douglas. Dune sand entering on the windward side is unable to obtain a lodgement and is soon swept across, becoming bleached in the process. Passarge[3] has suggested that pans may have been deepened or even perhaps wholly formed through the agency of herds of wild animals in drinking and wallowing and so removing substances in solution (chiefly carbonate of lime), and also mud.

The depression below the surrounding country is often slight, but it may exceptionally reach 200 feet. Krans Pan, Vogelstruis Pan, and Vogel Pan in Hopetown are sunk abruptly, the north-western rim in each case being a cliff capped with the calcareous tufa which covers the surrounding country. The escarpments, rising as much as 150 feet above the floor, are due to the crumbling away of the shales beneath the tufa, the materials being carried out by the prevailing north-westerly wind.

In the northern Karroo broad clay-flats have been developed along some of the shallow valleys—surfaces over which water moves slowly and which are locally known as "vloers" (floors). A number of the

[1] J. H. Wellington, *S.A. Geogr. Jnl.*, 1943, xxv, 50.
[2] F. Jaeger, in A. W. Rogers, *ibid.*, 1940, xxii, 55.
[3] S. Passarge, *Die Kalahari*, 1904, chap. xvii.

depressions in the north-western and northern Kalahari appear to have originated along ancient lines of drainage, just as has been suggested for chains of similar hollows in Western Australia. The Etosha Pan is 75 miles long and those of the Makarikari are comparable in size, all being fed by periodical rivers. The latter depressions have a greenish, siliceous, saline crust termed by Passarge [1] " salzpelit "

[1] *Die Kalahari*, 1904, chap. xxviii.

CHAPTER XVIII

PREHISTORIC MAN

Introduction. Cultural Periods. Pre-Chellean. Stellenbosch. Fauresmith. Middle Stone Age. Late Stone Age. Climatic Setting. Human and Humanoid Remains. Antiquity of Man. Literature.

Introduction.—Patient researches are disclosing in South Africa an ever-increasing abundance of Stone Implements shaped by Primitive Man, ranging from examples several pounds in weight down to tiny flakes, with varying degrees of finish. Many of such artefacts were found not on the surface but enclosed in lateritic ironstone or deeply embedded in gravelly deposits, sometimes in a waterworn or weathered condition. Flint was not available to their makers, and these tools are generally of hard, fine-grained materials such as quartzite, chert, lydianite, or silcrete, though of softer igneous rocks as well.

Work in Europe has shown that within the Pleistocene Epoch, a period to be measured probably in hundreds of thousands of years, Man was in existence, and that his progress was perpetuated by various stages in the development of his handiwork, or " cultures." That period coincided there with the " Great Ice Age," the several frigid and temperate phases of which were reflected in the characters of the corresponding faunas and floras, thus enabling a highly detailed scheme of chronology to be built up over the entire Pleistocene Epoch.

Not only is that Ice Age not manifest in South Africa, but the animal remains, with which the implements have occasionally been found, are too often, even when of extinct kinds, rarely of genera and never of species occurring in the north. With clear evidence available of the survival of certain forms into somewhat younger deposits—as in the case of the Mastodon discovered in the Vaal River Gravels below Barkly West, palæontological correlation with the corresponding stages in Europe is difficult to achieve and too frequently leaves a sense of uncertainty.

Cultural Periods.—The remarkable parallelisms with the assemblages found in southern Africa led for quite a time to the use of the European terms, though with the recognition that the several stages were not strictly synchronous in the two continents, such divergence becoming more marked towards recent times. Indeed, it is likely that certain of the stages either made their appearance in South Africa later than in Europe or endured longer, since there are reasons for regarding the " Bushman " as the descendant of one of the palæolithic

races of Europe. These people were still in the " rough stone age " when Europe had passed through the stages of polished stone (Neolithic), bronze, and iron implements. A local nomenclature has accordingly been built up by prehistorians from sundry isolated cultures that are being slowly co-ordinated. Thus far comparison with the European classification, as indicated tentatively in the following Table, is on a *typological basis and must not be deemed to imply more than a general contemporaneity.*

EUROPE			SOUTH AFRICA				
Period		Culture	Typological Equivalent		" Stone Age "	Geological Time	
Neolithic		(various)	Kitchen Midden	D	" Late "	Holocene or Recent	
Mesolithic			Wilton	D			
Palæolithic	Upper	Magdalenian Solutrean Aurignacian	Smithfield Stillbay Pietersburg, etc.	W	" Middle "	Upper	Pleistocene
	Middle	Moustierian Levalloisian Micoquian	Fauresmith	D D W D			
	Lower	Acheulian Chellean	Stellenbosch	W	" Early "	Middle	
		Pre-Chellean	Pre-Stellenbosch	D W		Lower	

W, wetter ; D, drier than normal.

While the precise stage of cultural evolution is normally decided by the shape of the implement, *i.e.* by *typology*, much weight is nowadays placed on the style of its manufacture, *i.e.* on *technique.*

Pre-Chellean or Pre-Stellenbosch.—It is reasonable to presume that cruder types would have preceded well-shaped forms. Apart from irregular rudely-chipped flakes the majority belong to a " Pebble-type " of industry in which simple pebbles have been flaked at one end or side, the more advanced examples including rough " hand-axes." Such pebble-types occur at the Victoria Falls (associated with rostrocarinates, beneath Kalahari Sand), the Pafuri River, Irene near Pretoria, Benoni, Vaal River, and East London. As J. A. Smuts, Jr.[1] has pointed out, such artefacts indicate a lengthy period that must go back to the Early Pleistocene at least.

[1] *T.R.S.S.A.*, 1945, xxxi, 39.

Chelles-Acheulian or Stellenbosch.—The outstanding product of this period was the large pointed "hand-axe," "coup-de-poing" or "boucher." These range from six to sixteen inches long, are rudely symmetrical and trimmed more or less regularly on one or both sides with an irregular median ridge, but without secondary flaking on the edges. Many of them made of quartzites are indistinguishable from those of the Lower Palæolithic of France and Spain.

In the earliest stage (Chellean) part of the original surface of the boulder has been retained to form the thicker end or butt. During the later stages (Acheulian) the hand-axe is still predominant, but a neater, smaller, yet more efficient tool (Fig. 69, 1 and 2), some being as finely shaped as the best Acheulian forms of Europe. Oval and flattened types as well as "cores" occur also. Important, too, has become the "cleaver," with one straight or slightly curved edge, and also implements made from large "Clacton" flakes—end or side, while "Levallois" flakes appear at a late stage. Such peculiar association of "core" and "flake" techniques is strongly marked in South Africa, though not unique.

This "great hand-axe culture" ranges right through Africa—at Victoria Falls, on the Bembezi and Umguza rivers, in Swaziland, in South-West Africa, and at numerous spots in the Union, such as in the Younger Gravels of the Vaal River. A feature is their extraordinary abundance in parts of the Western Province, embedded in the low-level lateritic ironstone deposits on the floors of the valleys or gentle slopes of the ranges or of the coastal plateau between Caledon and Knysna, as well as in the Transvaal and Natal. They are furthermore present in the Montagu Cave in the Cape.

The antiquity of this culture can be gathered from the fact that at Barkly West such implements, rolled and often worn down into the condition of pebbles, have been excavated in large numbers from a terrace the rock floor of which stands well above river-level. At Sheppard Island, Bloemhof, bones of the extinct elephant *Loxodonta* occur along with a Stellenbosch culture associated near Barkly West with a supposedly Middle Pleistocene fauna.

Fauresmith (Micoquian-Levalloisian).—During this period—divisible into two stages—the hand-axe, though commonly well finished—and along with it the cleaver—has become smaller and scarcer. At later times appear side or end flakes struck off from Levallois-type prepared cores and trimmed on one side only, with the "bulb of percussion" on the other (Fig. 69, 3 and 4), some resembling the "points" of the Mousterian. The majority are made of lydianite, some of the examples showing a strongly weathered crust, but the abundant Levallois-like examples from the Victoria Falls are of the glazed yellow and brown chalcedonic material of that area.

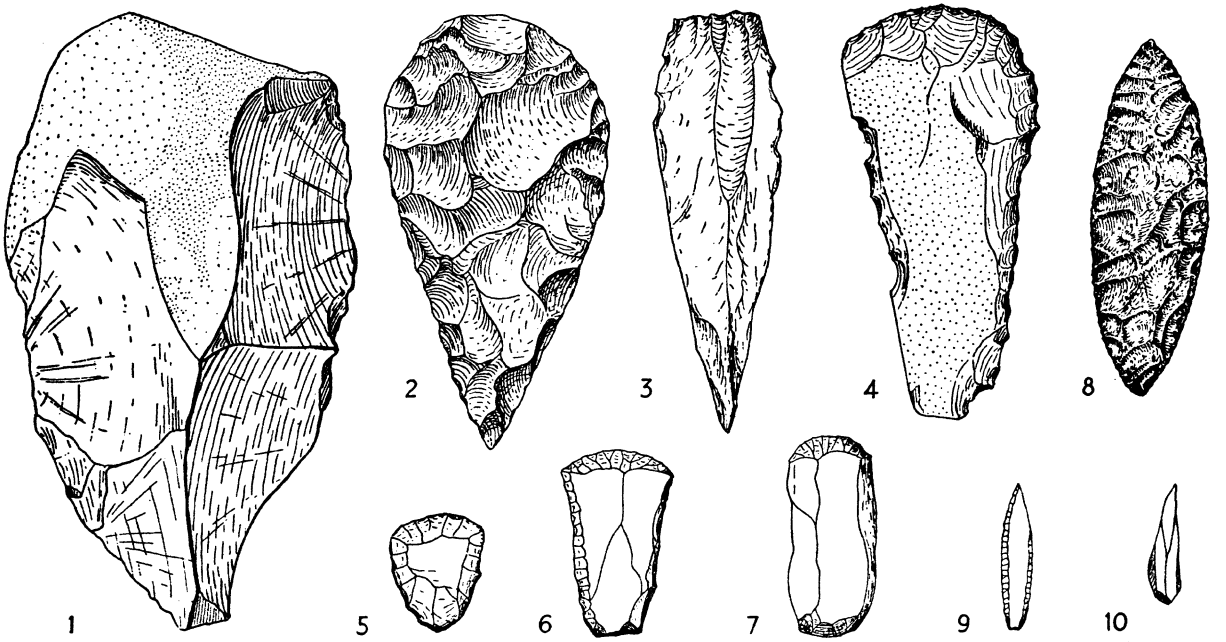


FIG. 69.—Types of South African Stone Implements:—1, Early Stellenbosch (Chellean) hand-axe (6 inches); 2, Later Stellenbosch (Acheulian) hand-axe (7 inches); 3, Fauresmith (Micoquian-Levalloisian) point (7 inches); 4, Fauresmith side-scraper (4 inches); 5, 6 and 7, "Middle Stone Age" scrapers (1½ to 2 inches); 8, "M.S.A." (Stillbay) (Solutrean) lance-head; 9 and 10, Wilton (Mesolithic) pygmy implements (1 inch).

This culture, which is widely spread over the interior, right to the coast about East London, has been found in several places to overlie deposits containing late Stellenbosch implements, *e.g.* Windsorton, Bloemhof, and Bambata Cave. Skeletal remains of this period have been recovered associated with bones of extinct animals such as *Equus capensis* and the buffalo *Syncerus* (*Bubalus*) *bainii*.

Middle Stone Age (M.S.A.) (Aurignacian-Solutrean).—Here have been included several developed industries—Glen Grey, Pietersburg, Howieson's Poort, Stillbay—the relationships of which are not always known. The implements, commonly of lydianite, show one smooth face and are dominantly scrapers of various kinds—disc-shaped, keeled, single, or double " duck-bills " (Fig. 69, 5-7), points and burins —neat pear-shaped or laurel-leaf-shaped lance-heads delicately worked on both sides (Fig. 69, 8), seemingly evolved from Mousterian points, and at a late stage tanged arrow-heads.

Where such implements do not rest on the ground, they can commonly be found in grit or ferricrete from two to over twelve feet below the surface. They overlie deposits having Fauresmith types on the Riet River (Orange Free State), Vaal River near Bloemhof, and other spots. Numerous " factory sites " have been located in the Free State and northern Karroo. The youngest, the Stillbay culture, first discovered in a cave south of Riversdale, seems to have been restricted to the southern littoral, though assemblages from Bambata and East Africa show certain resemblances.

Late Stone Age (Solutrean-Recent).—Very different from the Neolithic cultures of Europe are the Smithfield, Wilton, and later industries that have mostly been yielded by caves and rock shelters in the Cape and Rhodesia, supplemented by the sand dunes and middens chiefly in the Cape. The implements are dominantly pygmy forms (Fig. 69, 9, 10), minutely chipped crescents, thumb-nail scrapers, and borers, together with bored stones (" Bushman stones "), pounders, mortars, ostrich egg-shell beads, rough pottery and paintings, certain of the last on burial stones. These " Stone Age " industries seem to have lasted well into the Modern Period. Many skeletons have been recovered, chiefly of Bushman and Hottentot affinities. It has been supposed that certain of the peoples concerned were immigrants from the north.

Confined to the interior region are numerous " rock engravings " apparently of early Smithfield age. The abundant " rock paintings " on the contrary characterise the enclosing mountain region and are of late Smithfield or Wilton age, two main phases of artistic effort being discernible, covering seemingly a wide period. These paintings show astounding resemblances to the well-known ones of Spain.

Climatic Setting.—While it cannot be doubted that appreciable fluctuations of climate occurred in South Africa, the full number and

times of such oscillations have perhaps been more definitely asserted than the limited or dubious evidence would seem to warrant. Analysis suggests that south of the Equator those variations were neither universal, synchronous, nor always in the same sense.

Over the Vaal River Basin [1] and Southern Rhodesia *three essentially wet periods* would nevertheless appear to be indicated. The earliest one followed the Kalahari Sand and synchronised with the deposition of the older implementiferous gravels with their Stellenbosch cultures—about Middle Pleistocene. The first dry interlude is indicated by sand and calcrete, and in East Africa was marked by strong earth movements. The second wet phase produced the younger gravels with their Fauresmith culture, and was succeeded by aridity and accumulation of red sands—towards the close of the Upper Pleistocene. The last wet period corresponded with the Wilton culture—Holocene or Recent —with aridity thereafter and final return to normal.

Supporting evidence has been got from caves, though much has yet to be done in working out the climatic cycles, remembering that some of these variations must have been local rather than regional.

Human and Humanoid Remains.—While as yet but few fragments of early man have been discovered in South Africa, such finds have caused a decided stir in the world of science, though little can really be said about the Palæolithic races that must have inhabited this land. Incidentally typology alone will give little information concerning past racial evolution or migration.

Reversing the usual procedure and going backwards in time, we find the Bantu as a quite recent invader, and before him the " mixed," and in the " Late Stone Age " the " pure " Bushman. Amazing is the evidence that during a remote period Europe was inhabited by races with a culture extraordinarily like that of the South African Bushmen ; the resemblances have been well emphasised by Sollas, Boule, Peringuey, and others. The marvellous pictures in the Dordogne and northern Spain in their artistry, technique, and subject—mainly hunting scenes—are all reproduced in the " Bushman " paintings and gravings, while the statuettes display characters peculiar to the Bushman race. It has therefore been concluded that the Bushman is very probably the direct descendant of late Pleistocene Man. While in his earliest day he utilised large stone implements, he replaced them ultimately by smaller forms and by arrows, but his culture remained nevertheless " palæolithic."

The " Strandloopers " (beach roamers), who inhabited the coasts, are regarded by Shrubsole as ethnically older than either the Bushmen or Hottentots.

[1] P. G. Söhnge, D. L. Visser, and C. van Riet Lowe, *Union S.A.G.S.*, 1937. Mem. 35.

" Middle Stone Age " Man was widely spread and had " Boskopoid " characters. The Boskop skull, noteworthy because of its exceptional brain capacity, was discovered near Potchefstroom embedded at a depth of 4½ feet at the top of a layer of lateritic ironstone. It is considered by Haughton and Elliot Smith to show affinities with the Cro-magnon race of the Aurignacian, though certain characters have induced Broom to raise it to the specific rank of *Homo capensis* and to regard it as perhaps ancestral to the Bushmen.

Similar " Boskopoid " remains, associated with implements of that period and in several cases with bones of *Equus capensis* and *Bubalus baini*, have been recovered from coastal caves (Fishhoek near Capetown, Knysna, Zitzikama) and inland (Springbok Flats and Haagenstad (Florisbad) near Bloemfontein). The Florisbad skull, called *Homo helmei*, shows in addition Neanderthal and Australoid features and is certainly of high antiquity.

No human remains have been found along with " Early Stone Age " tools, but to that remote period almost certainly belongs the Rhodesian skull. Epoch-making was the finding in 1921 at the bottom of a deep cave at the Broken Hill Mines, north-western Rhodesia, some 60 feet below water-level and overlain by hundreds of tons, of the bones of animals, birds, etc., along with rudely chipped stone implements, of the famous skull of *Homo rhodesiensis* together with a part of another, thereby revealing the most primitive type of face yet known. The enormous eyebrow ridges, the characters of the nose, the vast size of the palate, and the low brain capacity indicate this. Rhodesian Man was in certain respects more primitive than Neanderthal or Levalloisian Man and displays certain australoid characters like those shown by Java and Pekin Man.

These finds pale before the disclosure of the amazing *Australopithecus africanus* described by R. A. Dart in 1925 from the secondary limestone of Buxton on the edge of the Kaap Plateau (see p. 531), quarried out at a vertical depth of 50 feet and at a distance in from the edge of the cliff of 200 feet. Known as the " Taungs Skull " and popularly hailed as the " Missing Link," this outstanding relic is considered to be a human-like ape perhaps ancestral to the *Hominidæ*. Associated with many extinct animals, and particularly with a primitive baboon, it may be of Early Pleistocene age. A related skull, along with parts of others, from the Sterkfontein Cave, Krugersdorp, has been named *Plesianthropus* by Broom. More remarkable is most of a skull called *Paranthropus robustus*—got in 1938 from the Kromdraai Cave, Krugersdorp, together with many mammals, mostly extinct—which though referable to the apes is, particularly in its palate and dentition, extraordinarily human. Clearly, during the earlier Pleistocene, as set forth by Broom and Scheepers,[1] anthropoid apes much resembling Man must

[1] " The South African Fossil Ape-Men," 1946. Transvaal Mus., Mem. 2.

have lived in South Africa under a climate approaching semi-aridity, according to Haughton.

Antiquity of Man in South Africa.—By some persons Man is thought to have been evolved in this continent, a view which the discoveries of *Australopithecus* and *Paranthropus* would strengthen. Nevertheless, all that can really be affirmed is that primeval Man was in existence here at an extremely early date, as indicated by primitive implements. The lengthy span of human occupation is shown most impressively within the Zambezi Valley through the deduction that the lip of the Victoria Falls must have migrated upstream from Gorge 5 to its present position since the beginning of the Chellean and its chasm cut back for five miles and to a mean depth of over 400 feet.[1] The Vaal River has in places cut its bed down by as much as 200 feet and shifted its course laterally by several miles since Man lived in the vicinity.

Literature.—The foregoing merely touches on the fringe of this fascinating though intricate and, so far as South Africa is concerned, rather knotty problem, and the reader is referred to :—

Neville Jones, *The Stone Age in Rhodesia*, 1926.

M. C. Burkitt, *South Africa's Past in Stone and Paint*, 1928.

A. J. H. Goodwin and C. van Riet Lowe, " The Stone Age Cultures of South Africa," *Ann. S.A. Mus.*, 1929, xxvii.

J. C. Smuts, " Climate and Man in Africa," *S.A.J.S.*, 1932, xxix, 98.

A. J. H. Goodwin, " A Commentary on the History and Present Position of South African Prehistory, with full Bibliography," *Bantu Studies*, 1935, ix, 291.

L. S. B. Leakey, *Stone Age Africa*, 1936.

R. A. Dart, " Fossil Man and Contemporary Faunas in Southern Africa," *XVI Intern. Geol. Cong.*, 1936, ii, 1249.

L. H. Wells, " Africa and the Ancestry of Man," *S.A.J.S.*, 1941, xxxvii, 58.

H. B. S. Cooke, " A Preliminary Survey of the Quaternary Period in Southern Africa," *Archæological Series*, No. IV, 1941.

A. J. H. Goodwin, " The Loom of Prehistory," *S.A. Arch. Soc.* 1946, Handbook Series No. 2.

in which an extensive literature is cited and discussed.

See various papers in *R.S.S.A.*, " Robert Broom Commemorative Volume," 1948.

[1] A. L. Armstrong, N. Jones, and H. B. Maufe, *Journ. Roy. Anthrop. Inst.*, 1936, lxvi, 331.

CHAPTER XIX

THE SOILS OF SOUTH AFRICA

Introduction. Chemical Aspect. Complex Nature. Profile. Climatic Evolution. Geographical Evolution. Classification. Alluvium. Æolian Sandy Soils. Sedentary Sandy Soils. Dry Steppe Soils. Brown Soils. Black Cotton Soils. Red Loams. Lateritic Soils. Former Geographical Conditions. Soil Maps.

Introduction.—With Agriculture playing so vital a rôle, the subject of SOIL EVOLUTION or PEDOLOGY acquires special importance—one intensified by the ever-growing problem of combating veld-erosion. Only the merest outlines can, however, be submitted.

Soils belong to two main classes :—

1. *Sedentary* (residual, primary, or eluvial), produced by the weathering *in situ* of the underlying rocks, and

2. *Transported* (derived), from materials brought from a greater or less distance by gravity, water, wind, etc., such as gravel, alluvium, colluvium (creep-wash), loess, or desert sand.

Types transitional between 1 and 2 exist and are indeed common in South Africa. While transported and such "*mixed*" soils cover almost one-half of this country, attention will have to be directed rather to the sedentary class, since they preponderate in the agricultural areas and since they have furnished much of the material for the second class.

Under preceding descriptions of certain of the formations short accounts have been given of the soil dominantly yielded by each, which will have served to shadow forth the general dependence of *soil character upon the solid geology*. To such an extent is this true that over wide stretches in Rhodesia and the Transvaal the geological boundaries can be and are mapped very largely by means of the soil characters with satisfactory results. In consequence quite a number of geologists and agricultural chemists have become imbued with the idea of the *complete dependence* of the characters of a sedentary soil upon the rock which it overlies and from which it has been derived. Actually, as shown below, almost identical soils can under special circumstances develop from quite dissimilar formations.

The geological formation merely provides the raw material from which the soil becomes evolved under the superimposed influences of position, climate, and organic life—vegetable and animal—and the peculiarities of the final product have largely been shaped by those other factors.

The physical conditions in South Africa have, however, proved antagonistic to the production of wide stretches of uniform soil. Everything has depended on the relative parts, ranging from trivial to dominant, that were played by the primary or geological and the secondary or physiographical factors.

The Chemical Aspect of Soil.—In the early part of the century an exaggerated importance was attached to the chemical analysis in soil investigations; but it has come to be realised that the physical characters are of vital importance and that the mechanical analysis, that is to say the determination of the absolute sizes of the particles and their relative proportion, may sometimes be of equal, if not of greater, utility. It also serves to detect any lateral or vertical movement of particles. The finer the state of subdivision, the greater the total surface available for reactions between particles, soil fluids, soil gases, and organic life.

The chemical analysis of the *colloidal fraction* usually differs, sometimes markedly, from that of the soil itself, its composition being important, especially the ratio of the silica to the sesquioxides. By testing successive levels the migration of acids and bases can be determined. Significant too is the pH value, which ranges from 5 in acid, through 7 in neutral, to 9 in alkaline types, and quite commonly varies with depth.

The Complex Nature of Soil —A vast amount of recent research has demonstrated that soils are very far from being simple substances; that in addition to grains of recognisable minerals there are granules of complex hydrated silicates with a groundmass composed of almost ultra-microscopic particles of *colloidal matter*, in the partially or wholly hydrated state. Chiefly upon the last-named substances depend the physical characters of the soil, also its water-absorbing and holding qualities, which in turn are remarkably affected by the relatively minute quantities of various salts held in solution in the ground-water, as well as by the substances deposited from such by evaporation—principally in the surface zone. Physical texture is of high importance. The tendency is for the ultimate particles to become aggregated to form " soil crumbs " with increase in pore space. Such crumb structure is most desirable for plant growth, but is readily destroyed, as during podsolisation.

The decomposition of the silicates is a *progressive hydrolytic process*, while between the fresh mineral and the final product comes a series of intermediate substances, often of crystalline structure. The micas show this best, replacement of the basal metal by hydrogen transforming them into acid salts with kaolinite as the end-product; but the same applies to the decomposition of the feldspars, epidote, garnet, etc. In the case of the amphiboles and pyroxenes carrying alumina,

the final clay, after having passed through a series of intermediate acid salts, is greenish and differs from kaolinite, being perhaps nontronite. The magnesium-bearing mineral, montmorillonite, has been identified in certain basic soils (van der Merwe, Bosazza). In the tropics even such clays are broken up, alumina is set free, and oxides of iron, manganese, and titanium accumulate in the soil. In certain cases liberated silica, soluble in potash, is present.

Each type of soil furthermore appears to have a special rate and manner of decomposing not only minerals but organic substances. The humus, for example, is very largely removed in laterite; in the lateritic ironstones it is combined with oxides of iron, etc.; in steppe soils it is fixed by lime and in some other classes by sodium compounds. Under certain conditions one base is replaceable by another, such as sodium by calcium, though it is doubtful whether zeolites are actually responsible.

The Soil Profile.—As a rule the covering is divisible into two fairly distinct portions :—the Upper, True Soil, Eluvial, or " A " HORIZON and the Lower, Subsoil, Illuvial, or " B " HORIZON, which passes gradually or abruptly into the weathered rock " C "; sub-horizons A_1, A_2, B_1, etc., can generally be made out. In certain types, such as the lateritic ones, the boundaries become less definite. The " A " Horizon is normally marked by leaching, but carries humus and plant foods and, although perhaps only a few inches thick, constitutes the normally *productive layer*. The " B " Horizon is signalised by accumulation of matter, but is markedly deficient in fertility. The relative thicknesses of these several layers naturally vary from point to point, and in rare instances there may be inversion, as when calcrete or ferricrete outcrops. Under scouring a thinning or even stripping of the valuable " A " horizon may result, wherefore the menace in South Africa of erosion. Generally, sections eroded down to a hard B layer can only be regenerated with difficulty and at expense.

The Climatic Evolution of Soils.—Theron and van Niekerk have pointed out that soils vary in their utilisation of rainfall and that the " soil climate " need not be identical with the "atmospheric climate." In the arid regions where, as a rule, mechanical disintegration predominates over chemical, the soils are more closely dependent on the geological formation and hence vary from coarse rubble through " gravels " and sands (often rich in fresh feldspar and in mica) down to fine loess-like deposits (sometimes spoiled for agriculture by an excess of secondary calcareous matter). Manifestly in desert regions rocks of the most diverse types can get covered up by materials swept down over them by cloud-bursts or brought in by the wind, as is the case in the Atlantic Coastal Belt.

In the more temperate regions drab and light brownish soils are

developed in the drier parts and darker brown, black, or reddish types in the more humid areas, with the tendency, of course, for the sandy soils to form on the more arenaceous, and clayey on the more argillaceous strata. The feldspars are only moderately weathered, the ferromagnesian silicates more so, while in certain localities the iron compounds have collected just beneath the surface in the form of a layer of lateritic ironstone or " hard-pan " ; in others the ferric oxide has largely been removed or reduced to the ferrous state.

In the tropical belt under the hotter and more humid climate the rocks have been greatly weathered, sometimes to surprising depths ; the leaching has been intense and the soils are high in finely-divided aluminous compounds, but deficient in lime, magnesia, and alkalies. The proportion of iron may not be high, the widespread deep red or chocolate colour being largely due to the very fine state of division of the ferric compounds. At the extreme end are found the " laterites," which can arise from nearly every kind of rock and which are generally of similar lithological and chemical composition, even though traces of the original mineral structure can still be detected in the lower parts of the mass.

Geographical Influences in Soil Evolution.—It must be recognised that, while in each climatic belt the soil material is progressing in its evolution towards the type characteristic of that zone, *not every soil has been able to attain to that final state.*

For instance, over flattish country evolution tends to be rapid, and the " end-product " will predominate, as with the black " turf " soils ; but on steeper slopes the surface is constantly being renewed by erosion and the soil will consequently be in a more *youthful* state. In this manner can be explained, for example, the contrast between the poverty of certain temperate plateau-soils and the fertility of most broken tropical country, where the impoverished surface is being continually removed, at the same rate in fact as the rock beneath is being rotted. On slopes exceeding about 10° sheet-flood erosion commonly exceeds soil-renewal. At the foot of such slopes there tend to accumulate, on the other hand, *colluvial soils*, marked by great diversity in particle-size (with possibly large rock fragments at the bottom), which because of their position, thickness, and moisture conditions are normally of value.

It will be gathered accordingly that many soils are only in *an immature or intermediate stage of development—endodynamic* they have been styled ; indeed, it is probable that in South Africa such imperfectly developed types are as abundant as *mature* or *ectodynamic* soils.

The rather sandy soils on the Bushveld Sandstone of the central Transvaal and Forest Sandstone of Rhodesia result apparently from the sweeping downwards by the rain of all the finest particles of clayey

matter set free by the breaking up of the soft sandstone, an action aided by the abundant growth of timber on this formation.

The influence of vegetation is, of course, of high importance in the evolution of a soil—in breaking up the rock, in facilitating chemical changes, and more particularly in contributing humus and thus supplying the soil with nitrogenous and other matters. The soils of this country are commonly deficient in organic matter, which fact explains the general lack of sharp distinction between *soil* and *subsoil* that is so marked generally in Europe.

On the contrary, salts of various kinds, chlorides and sulphates mostly (such as gypsum), sometimes " alkali," act injuriously and may ruin the ground for agriculture. The immense area of the Makarikari, north-west of Palapye, is composed of dark saline clays, while the majority of the pans in the Karroo are floored with soil of no value whatever.

Neither should one overlook the important part played by ants, earthworms, and rodents in bringing material up to the surface, not to mention micro-organisms[1]; few things strike the visitor so much as the enormous numbers of ant-hills in the landscape in certain parts of this country. Two peculiarities in the normal profile may be mentioned: the numerous large mounds of sandy soil or " heuweltjies " in the south-western Cape—Stellenbosch to Van Rhynsdorp—due supposedly to ants, with wind playing a part, and the curious basins or " kommetjies " of Kingwilliamstown, Pondoland, or Umzinto, caused by worms.

Classification of Soils.—From the foregoing it will be gathered that the classifying of the various types of soil cannot be a simple matter; indeed, whatever attempts may be made in that direction will assuredly come in for considerable criticism.

Much of the knowledge of soils in general has been drawn from their study in temperate countries; only during late years have detailed investigations been carried out in the more tropical regions. Moreover, while the general dependence of soil types upon climatic zones has been fully established, it has been insufficiently recognised that many soils are only progressing towards their final states—others again are of a mixed nature due to the wash or creep from higher ground or to wind-borne matter; indeed, in this country the wind has played a very important part in soil formation or in its modification.

In South Africa the bulk of the territory possesses a climate which ranges from temperate to only sub-tropical owing to the plateau-like character of the country, standing as it does high above sea-level; the extreme climatic belts are therefore unrepresented and accordingly certain corresponding soil types are absent.

[1] W. J. Lutjeharms, *S.A.J.S.*, 1946, xlii, 43.

The character of its soils can be regarded as having been largely influenced by (1) the rate of erosion of the products of weathering and by (2) the nature of such products, which in their turn have been determined by the intensity of the rainfall and of the sun, reflected again in the degree of mineral rotting and of leaching of the decomposing mass.

The following general scheme must serve as an introduction to the study of the various papers dealing with particular areas of this country, some of the most important of which are quoted below :—

(1) Alluvium.	(5) Brown soils.
(2) Æolian sandy soils.	(6) Black cotton soils.
(3) Sedentary sandy soils.	(7) Red loams.
(4) Dry steppe soils.	(8) Lateritic soils.

This is by no means a complete table, there being many intermediate classes ; only the principal types can be referred to, however, and in the scheme outlined certain soils of obviously diverse character have had perforce to be grouped together.

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J. J. Theron and P. le R. van Niekerk, " The Nature and Origin of Black Turf Soils," *S.A.J.S.*, 1934, xxxi, 320.

C. R. van der Merwe, " Soil Groups and Sub-groups of South Africa," 1941, *Union S.A. Dept. Agric.*, Chem. Ser. 165.

V. L. Bosazza, " The Petrography and Petrology of South African Clays," 1945 (Thesis, Univ. South Africa).

(1) *Alluvium.*—The relatively late uplift of the continent has deprived South Africa of navigable rivers (if we except the lower Zambezi) and the strips of alluvium are nearly everywhere narrow and

much interrupted. The largest is composed by the flood plain of the Zambezi, together with the Urema, Pungwe, Buzi, and Sabi "sunklands"; other tracts border Delagoa Bay, while the Okavango and Chobe traverse extensive river-flats. Within the Union only the larger rivers possess alluvial belts worthy of mention, whence the vital necessity for irrigation works.

With a moderate-sized drainage system, the variety of the geological formations and the diversity of the soils within the basin tend toward a sediment of rather uniform composition and of good fertility though normally immature. Upon the velocity of the river depends, of course, the grain-size of the transported matter, and in all alluvia there are alternations of gravels, sands, and silts. Some of the muds laid down may contain much colloidal clay, for example those of the Great Fish and Orange rivers, which, although rich chemically, are unsatisfactory from a physical standpoint; when ploughed up, so that the clayey layers become mixed with the sandy, the resulting soils may be good.

The alluvia derived from the regions of low rainfall in the Union are naturally of good fertility, though poor in nitrogen; but even in the regions of high rainfall and intense leaching, no small proportion of the sediment may have originated through direct erosion of the but slightly weathered rocks of the highlands or of the youthful soils on their slopes.

(2) *Æolian Sandy Soils.*—In the arid Atlantic belt there are vast stretches of sand, pale near the shore owing to contributions from the white coastal dunes, but becoming redder inland. This fringing tract forms the threshold to the Kalahari region, the red or greyish sands of which, together with the foregoing, predominate within an area covering no less than *forty per cent.* of South Africa.

In the central parts of this huge territory the sand is thrown into small dunes which are, however, largely fixed by vegetation; but towards its borders the sand becomes spread in a more even mantle, which is ultimately broken up into tongues and outlying marginal patches, as, for instance, in the central part of Rhodesia and of the Transvaal. These red sands have been derived from the prolonged wearing down of granitic and quartzose rocks principally, and their sub-angular to rounded grains are mainly of quartz, chalcedony, or chert (with some fresh feldspar in the coastal belt) and some mica and heavy minerals such as garnet, magnetite, tourmaline, zircon, etc.

The red colour is due to the pellicle of iron oxide on the surface of the grains, or penetrating into cracks therein, and where the sand has been subjected to the action of ground-water and the influence of organic matter, the ferric compounds have been reduced and removed, thus producing a white or grey soil. Such is the case not only along river beds and in vleis and pans, but also in the surface layers over

wide stretches of the sand-veld to the north-north-west of Bulawayo. Beneath much of this red soil there may be a layer of calcareous tufa—morphologically the B horizon—which from the agricultural standpoint may be objectionable when the sandy covering is rendered very thin. These red semi-arid soils, not having been subjected to leaching, may, despite their coarse quartzose nature and deficiency in nitrogen, be phenomenally fertile, only requiring irrigation in order to produce excellent crops; the Kimberley district is a good instance of this. Similar white, grey, or reddish sandy soils cover much of Moçambique Territory, in part derived from beach-sands.

(3) *Sedentary Sandy Soils.*—There are several fairly well-defined classes which together cover a very wide area and which in certain regions pass gradually into the rather similar ones of æolian origin.

(*a*) The youngest Karroo sediments have in the northern and central Transvaal and in Matabeleland, north of Bulawayo, furnished deep soils of pale sand in which the quartz grains are from 0·04 to 1 mm. in diameter and also well rounded, inasmuch as the parent sandstone itself appears to have been largely of æolian origin.

The proportion of clay is low, as most of the fine matter furnished by the weathering of the feldspar grains has been carried downwards by infiltering rain and the fertility is therefore low. Such areas of heavy sand are as a rule dry and waterless, but nevertheless support a thick growth of timber; indeed, in Rhodesia the underlying rock is actually known as the Forest Sandstone, in the Transvaal as the Bushveld Sandstone.

(*b*) The Table Mountain Sandstone of the Cape, under a rainfall of from 20 to 35 inches—with more on the mountains—mostly in the winter, and a temperate climate, yields porous acid soils of low fertility (p. 247) since the parent strata are quartzose. They are podsolic with a dark grey leached A horizon, and may have had iron deposited below. Juritz has emphasised the generally low proportion of plant food in these soils, which can, however, be used for growing timber, as at Knysna, George, etc.

The Waterberg beds give brown, sandy, loose and pervious soils, which have no distinction between the A and B horizons, and soon dry out; they are sour, poor in lime, phosphoric acid and organic matter.

(*c*) Of wide distribution in Rhodesia, central and northern Transvaal and Natal are grey or pinkish soils derived mainly from the Old Granite and Gneiss. They are gritty, owing to the release of irregular grains of quartz, while the feldspar fragments are partly weathered. In places they are podsolic with some lateritic ironstone below. In the areas of heavier rainfall they may become water-logged. Where the parent rocks are hornblendic, a deep-red colour prevails and the texture is finer and more loamy.

Such podsolic soils, mainly residual, have been developed upon Karroo beds around Basutoland and the east and north of the Free State and Transvaal Highveld under a rainfall of 20-35 inches. They show a grey-brown siliceous A horizon with scattered concretionary ironstone pellets resting on the greyer and more clayey B horizon. Rather similar types characterise the " Sugar Belt " of Natal into which the Table Mountain Sandstone enters largely.

While somewhat sour, all these soils are moderately well fitted for agriculture, owing to the feldspar and mica from the parent sediments, to lime from the dolerite intrusions and to clayey products from the more argillaceous strata; indeed, some types are more loamy than sandy.

(*d*) As stated in Chapter VII the prolonged solution of the Dolomite has led to the accumulation of a mantle made up of the insoluble portion, so that the parent rock is largely concealed by a certain amount of chert-rubble capped by a dark red siliceous soil frequently stained by, or carrying loose pellets of, oxides of iron and manganese. This individuality is maintained even when transgressing from one soil-region to the next—*i.e.* from east to west. As developed around the Rand, such soils are rather poor, being deficient in alkalies, phosphoric acid and, paradoxically, in lime. In the area of lower rainfall in the western Transvaal and over the Kaap Plateau carbonate of lime has been redeposited in the subsoil and the soils may be calcareous and of little value.

(4) *Dry Steppe Soils.*—Typically drab, brownish, or sometimes brownish-red soils characterise the Karroo region from the Cedarberg on the west and the Zwarteberg and Zuurberg on the south. Appropriately they are known as " Karroo soils," but they gradually pass in a north-easterly and easterly direction into the brown type (5).

(*a*) Typically at or just below the surface are found the strata in process of reduction to small fragments—largely by insolation—the disintegrated material being only very imperfectly weathered. The soil is thin—with little distinction between the A and B horizons—and often wanting, while the vegetation consists principally of small bushes (*Pentzia*) and other shrubs of the Karroo flora; grasses are as a rule restricted to areas invaded by sand. Calcareous matter is common, either in the form of pellets within the soil, or collected deeper down as nodules and sheets. The redder types are mostly sandy.

Along some of the shallow valleys the soil is uniformly drab in tint and is largely æolián or fluvio-æolian in origin, being indeed comparable with the loess of the Mississippi valley in the United States. The prevailing winds have picked up fine particles of dust from the surfaces of the numerous clay pans and " vloers " and spread them far and wide; minute grains of sandstone, shale, surface limestone, and dolerite can be recognised under the microscope.

The Karroo soils are renowned for their fertility under irrigation, being rich in slightly weathered rock-material, in lime, alkalies, and phosphoric acid, but low in humus, as would be expected from the low rainfall (from 5 to 18 inches) under which they have been evolved. Continued irrigation may, however, bring about " brackness " where these soils are thin and overlie compact rock ; drainage and careful cultivation may then become necessary.

(*b*) In certain districts, *e.g.* Van Rhynsdorp, Swellendam, and Oudtshoorn, the reddish sandy loam has for a depth of one or more feet been converted into an intractable hard-pan known as " *dorbank*," due to accumulation of silica in the presence of a high salt concentration, with subsequent dehydration under a semi-arid climate.

(*c*) In the central Free State a *solonetz-type* has been developed (van der Merwe) on Beaufort beds, a greyish sandy loam, acid in the A and alkaline in the darker clayey B horizon, with carbonates of lime and soluble salts. It may contain montmorillonite.

The Steppe type extends northwards into South-West Africa and Griqualand West, and also eastwards into the Orange Free State and Transkei, where it passes into browner or blacker soils, the change being brought about not so much by geological differences as by the higher rainfall and the slightly greater content of organic matter.

(5) *Brown Soils.*—Under this head have perforce to be included several classes both eluvial and colluvial, although differing among themselves in certain and sometimes important particulars. They have all been formed under temperate conditions and under a precipitation of from 20 to 30 inches, but are poorly represented in this country and by no means typically, because of their general deficiency of humus.

(*a*) As a special type are the rather clayey soils formed from the Malmesbury slates in the Western Province. Derived from somewhat unfertile rocks, possessing small water-retaining capacity, occurring on flattish ground and leached under a rainfall of from 18 to 30 inches during the winter months, they are distinctly low in lime, potash, and phosphoric acid, and unfortunately sometimes high in sodium and magnesium compounds ; in places, however, they have been enriched by detritus from the granitic hills of this region.

(*b*) Those produced by the Bokkeveld slates are much better, because they occupy a less worn-down area and are generally confined to the valleys, where their clayey properties are counteracted by sand derived from the quartzite ranges adjacent. As the rainfall is lower than over the coastal belt generally, and as the slates of the Bokkeveld contain more plant food than those of the Malmesbury Series, the soils are decidedly more fertile. Indeed, in some places, for instance in the Oudtshoorn district, lands formed by the ploughing up of the weathered micaceous slates can be used immediately for growing crops.

(*c*) Dark brown soils are found at intervals in parts of the Transkei, East Griqualand, Natal, northern Free State, and southern and eastern Transvaal, but modifications are commonly brought about locally by the presence of either sandstone or dolerite, which respectively confer on them either a light, porous, and frequently sour character, or the more desirable red loamy quality. Those situated inside the Lebombo are thin, have been formed under high temperatures with occasional downpours, and do not show marked horizons (van der Merwe).

(6) *Black "Cotton" Soils.*—Developed within the central Transvaal, Southern Rhodesia, and Portuguese East Africa, this type is known to the Dutch farmer under the name of "*Black Turf*" from its peaty aspect, although the proportion of organic matter is in no respect high; for this and other reasons Marbut's comparisons with the "Tschernozem" soils of Russia are unsatisfactory, for the amount of humus is surprisingly low, though of a peculiar kind.

As mentioned already, such black earths have been formed upon more than one kind of rock and several classes are known.

(*a*) *Norite "Black Turf."*—Composing the sparsely wooded portion of the Bushveld region, the soil has a thickness of several feet through which project here and there lumps of fresh norite—in places flat surfaces or knobs of solid rock. It is highly tenacious and most intractable when wet, but friable in the dry season; yet just below the extensively cracked surface it may still be quite damp. It rests on decomposed norite (or pyroxenite), soft, white and friable; characteristic is the presence of carbonate of lime in grains or pellets, particularly in the B horizon and in the powdery stuff below. Smit, Marchand, and van der Merwe have shown by mechanical analysis an uncommonly high proportion of clayey matter—from 40 to 60 per cent.—with a high volume-expansion, which explains their extraordinary moisture-retaining power and impermeable nature when wet. The colloids include apparently minerals of the montmorillonite group. The soils have been formed by the exhaustive weathering of the lime-soda feldspars and pyroxenes of the norite with the production of clay and carbonates of lime, magnesia, and soda, and gypsum, *in situ*, on gently undulating ground under a rainfall of from 20 to 25 inches and a climate approaching sub-tropical. While usually neutral, they are curiously high in silica in all profiles. They are comparatively low in ferric oxide and poorly supplied with organic matter and nitrogen, but have a good potash content and form good soils agriculturally, though difficult to manipulate when moist.

In Southern Rhodesia, on the great basic dyke which traverses that country from the Umvukwe Hills in the north to the Doro Hills in Belingwe, red and black soils have been developed which are rich in

magnesian compounds derived from the magnesian silicates of the intrusion, while the vlei limestones in the neighbourhood are high in magnesium carbonate too. The fertility has been seriously reduced by this excess of magnesium compounds.

(*b*) *Basalt Soils.*—A very similar type of black or chocolate soil, only scantily wooded, covers the basaltic portions of the Springbok Flats, those of the inner side of the Lebombo from Zululand northwards to the Zoutpansberg, those of the Tuli and Palapye areas and the volcanic plains to the north of Bulawayo.

Those on the Springbok Flats are identical with the soils from the norite in their calcareous subsoil, high potash, but low nitrogen content (Marchand).

They are strikingly like the " regur " or black cotton soil of the Deccan region of India, formed on basalt and very fertile despite its low nitrogen content ; they also recall the broad stretches of dark soil in British East Africa on the lavas of that region.

Those of Barkly East and Basutoland are granular, and show signs of frost action and are well supplied with humus, but without carbonates.

(*c*) *Granite and Gneiss.*—Large parts of Rhodesia and also the undulating area in north-western Rustenburg formed by granitic and hornblendic rocks are partly covered by dark " turf " soils of similar nature to those described, even to the pellets of limestone. They are scantily wooded, but are bordered by tree-covered tracts possessing a red sandy soil resting on gneisses in every way similar to those underlying the turf.

(*d*) *Karroo Shales.*—To the north of the Pretoria Saltpan there exists an outlier of Karroo beds, the blackish shales of which have produced a zone of " turf " soil ; the calcareous concretions in the latter have been derived from the bands and nodules of dark limestone in the underlying strata. The same is the case with the Madumabisa Shales in the area well to the north of Bulawayo. In Vredefort, Heidelberg, Standerton, Bethal, and Ermelo districts, and probably elsewhere too, dark grey but more sandy soils are found that are in some ways transitional between the above and the brown types represented more to the east with which they are frequently associated. They are underlain indiscriminately by shales, sandstones, or dolerite and are fairly high in organic matter.

Many of the so-called " vlei soils " are of this dark tenacious type and, so far as can be judged, Maufe is probably correct in stating that they have been developed in areas where there are alternations of w and dry seasons and in situations where there is imperfect draina such as would promote extreme decomposition of the rock below. Litt leaching has taken place and the B horizon is often poorly developed. A high rainfall is not essential, 15 inches being often sufficient, for the

alkaline carbonates set free through rock-weathering would favour the production of colloidal substances and consequently the development of a soil with retentive properties. Indeed, owing to insufficient aeration around their roots, trees do not do well on this class of ground and hence such land is never well timbered. On the higher ground, with freer drainage, the soil commonly changes to chocolate or red and becomes more porous and ferruginous but somewhat less calcareous.

(7) *Red Loams.*—Maufe has remarked upon the wide distribution of this type in Southern Rhodesia, characteristically on the extensive belts of " greenstone schists." They have been evolved under a rainfall of from 25 to 40 inches in a climate inclining towards sub-tropical, and in country of undulating topography. The deep-red surface layer changes rapidly, though irregularly, into yellowish-brown clayey matter below, and that in turn into decomposed rock, brown at first and then greenish. Unlike the black soils, leaching has removed most of the lime, magnesia, and alkalies produced by rock-weathering (*vide* 6) ; they are transitional between immature red soils with adequate food content and the mature, lateritic, and less fertile types.

Instructive are the red soils on the norite to the north-west of Pretoria, intimately associated with the " black turf " ; they are always high in detrital magnetite and in some cases are certainly derived from more pyroxenitic varieties of the norite. Smit and Marchand have shown that, although appearing to be sandy, they actually contain from 30 to 45 per cent. of clay owing to the high content (7 to 10 per cent.) of finely divided ferric oxide, which has acted as a deflocculant and radically altered the texture of the soil, which is leached and aerated ; moreover, despite its red colour, it carries fully as much organic matter as the black variety.

The red loam of Koedoespoort, near Pretoria, formed on diabase, is identical therewith, and most of the deep red and chocolate soils formed upon the dolerite in the Transkei, Natal, and Zululand are doubtless similar in their character. Much of the soil on the diabasic lavas of the Ventersdorp System in the southern and south-western Transvaal is reddish, but of a sandy rather than a loamy nature owing to the abundance of quartz and agate—from lumps down to minute particles —derived from the silica-infilled amygdales of those rocks.

(8) *Lateritic Soils.*—True *laterite*, that is to say a bauxitic material containing free hydrated oxides of alumina and iron, is known only from the highest peneplain of Nyasaland ; but *lateritic red earths* grading into (7) are represented north and south of the lower Zambezi, and intermittently along the Great Escarpment to about Basutoland, under high rainfall (35-65 inches), temperature and internal drainage. Downward variation is gradual. The colloidal fraction is high in oxides of iron and aluminium. They are developed on varied formations—on

gneiss, on dolerite (Natal), and on dolomite (Sabi). The subsoil is infertile, and this poverty in plant food compels the trees to send their roots deep down in order to obtain their nourishment from the deeper seated and less decomposed rock material (see p. 450).

The *Yellow Lateritic Earths* have formed in south-east Transvaal highveld, East Griqualand and central Natal—including the " wattle belt "—under a high rainfall and cold dry winter (van der Merwe). The colloids contain some free alumina.

Influence of Former Geographical Conditions.—It is probably insufficiently realised that geographical conditions have not been stable, that certain soil types are in a stage of transition, and that some may still retain traces of vanishing or now vanished environment. For example, it is pointed out (Chapter XXI) that more arid conditions seemingly prevailed in the past over South Africa, that the Kalahari Sands formerly covered a wider area and that they have been reduced to their present limits by erosion ; remnants of the sands for instance are still preserved in eastern Rhodesia. The denudation of these outlying coverings has contributed grains of quartz and chalcedony to the sedentary soils of the neighbourhood and so appreciably modified them. A similar action must have gone on elsewhere, and it can be suggested that to the north of Pretoria some of the deep red sand overlying the norite may have had such a foreign origin, and that the area of black turf is gradually being extended.

Cooke has pointed out that in many localities Middle Stone Age implements are abundant in or just above ferricrete underlying the A horizon, and suggestive of a " fossil soil."

Some of the extraordinary deep red and chocolate sands of the coastal belt running through Natal, Zululand, and Portuguese East Africa, which rest equally on formations ranging from Archæan to Tertiary, may perhaps be dated to this inferred climatic fluctuation. Most of the iron has been derived from ilmenite, but a little could have been furnished by glauconite from the Cretaceous rocks.

On the other hand, wind-blown sea-sand and the red arid sand of the lower Olifants Valley are invading the coastal belt in the south-west of the Cape and coming to modify the residual soils of the Malmesbury and Bokkeveld Series. A rather similar action is affecting the Kimberley district and the western Free State, red sands partly from the Kalahari and partly from the sand-banks along the bed of the Vaal being spread in a south-easterly direction over areas of shales by the prevailing winds.

On a smaller scale in its action, though perhaps of greater moment to the agricultural community, are those changes that have been brought about indirectly as the consequence of habitation of the country during the past century, namely the draining and drying out

of vleis together with over-stocking, which have brought in their train erosion and all its evils.

Soil Maps.—Attempts have been made from time to time to picture the distribution of the chief soil types in South Africa.

In that by Marbut, insufficient importance has been attached to the action of the wind, and the lines have been so drawn as unduly to emphasise the dependence of soils upon the climatic zones ; particularly is this the case with the Kalahari region. In no small degree the map merely depicts areas within each of which a certain type of soil would have formed under *normal conditions*, unhampered by the interferences brought about by the formation of calcareous tufa, accumulation of alkali, invasion (past or present) by æolian sands, etc., while, singularly, insufficient recognition has been given to purely geological factors.

No map has been made for Rhodesia, but one by Dr C. R. van der Merwe of the Section of Soil Survey of the Union depicts the broader classes as follows :—Desert soils of the west ; solonetzic types of the central Free State ; Kalahari Sand and Limestone ; subtropical black clays of the Bushveld and brown sandy soils of the Lowveld ; light and dark brown sandy soils of the Transvaal ; black clays of the Drakensberg ; Highveld prairie soils ; semi-coastal belt soils of the Eastern Province ; coastal belt soils of Natal ; laterite and lateritic red earths and lateritic yellow earths along the eastern Escarpment ; littoral sandy soils ; and the varied types of the winter Cape region of the southwest and south.

A plan closely paralleling the Rainfall Map has thereby resulted, though a great amount of generalisation has been inevitable. While the general scheme commends itself, local conditions have played no small part and have brought about many deviations from the ideal. For South Africa Pedology cannot be divorced from Geology and any system of Soil Classification must involve both the geological as well as the climatic factors. For instance, the dominant character of the Bushveld " turf " is geological, since it is almost restricted to the norite formation, but, wherever the surface rises slightly so that drainage has been possible, flocculated red loams take its place. In broken country, such as central Natal, each regional zone is interrupted by the transverse valleys with their drier soils and vegetation.

Again it is questionable from the agricultural viewpoint whether soils belonging to the same class with comparable profiles rank equally, for instance those of the Pretoria Series, when derived from quartzite or shale groups respectively, or of the Bushveld Granite, even under similar environments. Only in the very broadest manner does it seem possible to indicate on a map the distribution of the principal kinds of soil within this immense and varied territory.

CHAPTER XX

ECONOMIC GEOLOGY

Introduction. Igneous Origin of Ores. Periods of Mineralisation. Principal Mineral Deposits (arranged alphabetically).

Introduction.—The vastness of the mineral resources of South Africa has been insufficiently realised. Centuries ago this country was famous as a producer of gold, and the multitude of ancient workings for that metal and also many for copper and tin testify to the active exploitation of its mineral wealth in remote times. To-day South Africa is a big producer of the world's diamonds and furnishes one-third of the world's gold; Rhodesia stands high in its output of asbestos and chrome-iron ore; moreover, the annual tonnage of coal is tremendous, its cost of mining still fairly low, and the reserves thereof enormous.

The mining industry, of which we should certainly be proud, has unquestionably been the cause of the phenomenal development and prosperity of this great country and will undoubtedly be its mainstay for years to come. More and more too will the mining geologist have to be guided by the principles of mineralogenesis and petrogenesis in dealing with such problems as the persistence of ore-bodies, the question of local enrichment, the dependence of their characters upon the geology, etc., just as it will fall to the metallurgist to devise methods for the economic separation and treatment of the lower grade and more complex ores. Attention will have to be paid more particularly to the finding and exploitation of the less common kinds of the baser metals, for example, tin, tungsten, nickel, chromium, vanadium, etc., the market price of which will gradually rise with the ever-increasing demand, and of such minerals as mica, fluorite, apatite, beryl, lepidolite, monazite, etc. There are many tracts that have scarcely been trodden by the prospector, for example parts of the Namib, Kaokoveld, the outer borders of Rhodesia and of the adjacent territory of Moçambique. What are particularly desired are numerous small workings like those of Southern Rhodesia.

The Igneous Origin of Ores.—Excluding the stratified ore-deposits, such as coal, asbestos, iron ore—perhaps also the Rand bankets—and secondary concentrations such as pyrolusite, the

bulk of the important ore-bodies in South Africa are connected either directly or indirectly with igneous intrusions, and their existence and nature are intimately bound up with magmatic activity. A discussion on the origin of the metallic ores generally will be found in any text-book on Ore Deposits, wherefore it will suffice to remark that small amounts of metallic sulphides and oxides must originally have been disseminated through the majority of igneous magmas, which during the process of differentiation and crystallisation have tended to become concentrated in certain portions of the magma. They may conceivably have been derived from the trace-minerals contained in pre-existing sediments assimilated by those magmas. In the case of basic " melts," the sulphides and oxides seem generally to have segregated and crystallised along with the silicates, often at or near the base of the body, giving rise to the " *magmatic ores*," of which the chromitites and nickeliferous pyrrhotites form examples. In the acid " melts," however, in which a concentration of volatile " mineralisers " was brought about, tending to lower the temperature of crystallisation, the sulphides and oxides collected generally in the still-liquid fraction and are hence found either in the late crystallising pegmatites traversing the plutonic body, as pegmatites and quartz veins cutting the country rock, or as impregnations along or near the contact with the latter. They are hence most common within the zone of contact metamorphism surrounding such plutonic bodies—especially " cupolas "—but sometimes occur just within the margin of the latter. Only occasionally have lodes been cut by younger granitic phases. An important part was moreover played by the country rocks, the formation most favoured in Rhodesia, for example, being the ancient " Greenstones."

Mixed gneisses or " migmatites " are, on the contrary, mostly barren. Many of the common " fissure veins " are believed to have obtained their mineral contents by the action of heated waters ascending through zones of fracturing from still deeply buried bodies of cooling magma. At the one extreme, therefore, are the deposits that have crystallised from a molten silicate magma, at the other those formed from dilute aqueous solution, probably in many instances almost at normal earth temperatures.

Periods of Mineralisation.—1. The EARLIEST of the deposits known are represented by bodies of chromitite—magmatic differentiations within the ultrabasic rocks associated with the Schists of Southern Rhodesia, as at Selukwe.

2. The PRINCIPAL PERIOD for South Africa followed, which accompanied the intrusion of the Old Granite and Gneiss in its two or more phases, particularly in Manicaland, Rhodesia, and the northern and eastern Transvaal far back in the pre-Cambrian. The majority of such lodes traversing the Primitive Systems are auriferous, though with subordinate amounts of silver, lead, copper, antimony, and tungsten, and are replacements, impregnations, or fissure-veins carrying sulphides and sulph-arsenides and are often of a refractory nature metallurgically. More than one period of ore-formation is represented.

Notable are the abundant pegmatites of this period carrying cassiterite, tantalite, etc., of the Erongo area, South-West Africa, and of Namaqualand. The interaction between acid offshoots and ultrabasic country-rocks has led in certain cases to the forming of corundum-bearing types, *e.g.* at Leydsdorp and Pietersburg, and to the pyroxenites containing apatite and vermiculite at Palabora. Consequential are the seams of chrysotile asbestos in serpentine of Rhodesia and Swaziland.

3. Of subsequent, though of pre-Nama age, are the abundant intrusions carrying the copper deposits of Namaqualand, hitherto regarded as of magmatic origin, but apparently metasomatic.

4. The SECOND GREAT PERIOD—perhaps late pre-Cambrian—was brought about by the introduction of the huge basic sheet of the Bushveld region, which in the course of its differentiation gave rise to two zones rich in chromite and in magnetite respectively. Associated with the former and also following a rather definite horizon somewhat higher up in the norite is platinum, while types near the Pilansberg containing sulphides carrying nickel and copper are also of a magmatic origin. The chromitite bands and the platiniferous horizon in the Great Dyke of Rhodesia form a marked parallel with those of the Bushveld, being presumably of the same age. The succeeding Red Granite—or one or more phases thereof—charged originally with volatile compounds, was responsible for the local mineralisation of the roof of the Bushveld Lopolith, as shown by the presence of ores of tin, tungsten, molybdenum, bismuth, copper, and arsenic, accompanied by fluorite, tourmaline, topaz, monazite, etc. The Younger or Cape Granites, of possibly similar age, display a weak mineralisation by cassiterite and sometimes arsenopyrite. Genetically connected are the bedded gold " veins " of Pilgrims Rest and the vertical gold reefs of Malmani.

5. The great copper-lead deposits in the Otavi Dolomite are presumably of post-Nama age, though unconnected with any known granite bodies.

6. The THIRD PERIOD is linked with the post-Matsap movements and has been responsible for the extensive deposits of iron and manganese ores and amphibole-asbestos in the Cape and Transvaal.

7. The FOURTH PERIOD, at the close of the Stormberg volcanicity, appears to have produced the copper ores at Messina and, through differentiation, the magmatic copper-nickel-pyrrhotite ores at Insizwa in East Griqualand, and has been responsible for some at least of the lodes in the south-eastern corner of Rhodesia. Somewhat later are the post-Karroo quartz-veins, carrying platinum near Nylstroom and gold at Port St Johns and Knysna.

8. The FIFTH PERIOD saw a revival of magmatic activity at the end of the Cretaceous that led to the production of the multitude of Kimberlite pipes, in certain of which the diamond is found.

The Principal Mineral Deposits.[1]—The succeeding account is admittedly a brief one, but it is impossible in these few pages to do justice to the subject, which is an enormous one with a wealth of literature, scattered unfortunately through a host of publications, many of them mining or financial periodicals.

Antimony.—Lodes of Stibnite are known in Rhodesia near Bulawayo, Belingwe, Umniati, and along a line running east from Que Que, as at the Gaika Mine, and in the Transvaal near Barberton and in the northern set of reefs of the Murchison Range near Leydsdorp, the mineral there being present as slender needles aggregated into bunches and veins in lenticular bodies of quartz and carbonates in basic schists (p. 40). These various deposits are mostly auriferous and have been worked almost entirely for their gold. The output of antimony from the Transvaal for 1951 was 28,211 tons, valued at £3,500,000.

Arsenic.—Many of the auriferous deposits in both Rhodesia and the Transvaal contain arsenopyrite (mispickel), *e.g.* the Arcturus and Slate Mines near Salisbury, Gaika Mine at Que Que, Hydra Mine at Gwanda, New Consort Gold Mines near Barberton, and some near Lydenburg, while this mineral is furthermore associated with cassiterite at Stavoren in the east of the Bushveld. Little of the arsenic is being recovered from the concentrates of the various mines in spite of the great consumption of arsenical dips in this country.

Asbestos.—Pioneered by the workings of Griqualand West this industry has taken great strides, Southern Rhodesia being to-day in the lead with a total production up to the end of 1951 of 1,470,043 tons valued at nearly 42 million pounds, that of the Union being valued at nearly 24½ million pounds.

[1] In addition to the references given under the particular headings, the following general works can be consulted :—

Union S.A. Official Year Book (with bibliography), published yearly.
The Mineral Resources of the Union of S.A., 1940.
Handbuch der regionalen Geologie, 1929, vii, 7a.
S. Rhod. G.S., 1947, Bull. 38.

Under the name " asbestos " are included the two very distinct classes of mineral, A. *Chrysotile asbestos* and B. *Amphibole asbestos*, the latter in turn divisible into Crocidolite, Amosite, Tremolite, and Anthophyllite. Each kind has its own field of employment. The genesis in each case forms a most interesting study.[1]

A. CHRYSOTILE.—(1) White " cross-fibre " asbestos is exploited on Diepgezet and other farms near Carolina, Transvaal, from lens-like bodies along 20 miles of outcrop upon a horizon just above a diabase sill in the top of the Dolomite. The latter has been converted thereby into serpentine, and under the expansive stresses set up during hydration numerous fractures parallel to the bedding have been formed within which the chrysotile has crystallised with fibres set transversely to such planes. When very closely spaced the material is known as " ribbon rock." The average width of seam is only about half an inch, but the fibre is white, silky, and of superior quality. An identical deposit occurs near Kanya, Bechuanaland.

(2) At Kaapsche Hoop in the Barberton district the mode of occurrence is quite different, the chrysotile being found along more or less well-defined horizons in a body of serpentine intrusive in the Barberton beds, the parallel seams being spaced so closely that over a width of up to 15 feet there may be as many as from 10 to 30 bands per linear foot. The important Havelock Mines, just across the Swaziland border near Pigg's Peak, are working high-quality parallel and cross-cutting seams in a long zone in serpentine averaging 110 feet wide and dipping at between 40° and 60° with a yield of about 4 per cent. ore. The conditions recall those in Rhodesia. The mineral is transported to Barberton by an aerial rope-way 12½ miles long.

(3) In Rhodesia [2] chrysotile is found in veins which cut through masses of ancient serpentine, with greater or less regularity, often seaming the rock in every direction with the fibres set perpendicular to the walls, just as in the Canadian fields; the workings therefore resemble great quarries. The mineralisation is ascribed to the intrusive granite; towards the footwall both rock and seams become talcose. The largest producer is the Shabanie of the Shabanie-Nil Desperandum group of mines to the north-east of Belingwe, while to the west of Victoria, near Mashaba, lies the Gaths-King group.

[1] P. A. Wagner, " Asbestos," *S.A.J.I.*, 1917, i, 251-70. A. L. Hall, *Asbestos in the Union*, G.S. Mem. 12, 1918; *T.G.S.S.A.*, 1918, xxi, 1-36; 1921, xxiv, 168-81; 1923, xxvi, 31-49, wherein the previous literature is referred to; *S.A.J.I.*, 1924, vii, 724; M. A. Peacock, *Amer. Miner.*, 1928, xiii, 241; L. Reinecke and L. McClure, *T.G.S.S.A.*, 1933, xxxvi, 29; *Min. Res. Union S.A.*, 1940, 320; A. L. du Toit, *T.G.S.S.A.*, 1946, xlviii, 161.

[2] F. E. Keep, *S. Rhod. G S.*, 1929, Bull. 12; *Third Empire Min. Metal Congr.*, 1930.

(4) In Umvukwe, Rhodesia, nearly vertical veins of this mineral traverse the serpentine of the western edge of the " Great Dyke."

In all these types of deposit the soft blue or green rock with its narrow veins of cross-fibre chrysotile is mined in bulk, crushed, and the fluffy white mineral separated from the serpentine matrix by mechanical means ; a length of under a quarter of an inch can be extracted at a profit at most of the mines.

B. AMPHIBOLE ASBESTOS.—(*a*) *Cross-fibre Kinds.* Seams of *Crocidolite* and *Amosite* have been developed under metamorphism in the jaspery ironstones of the Transvaal System (p. 158) by recrystallisation *in situ* of ferriferous layers strictly following the bedding. They range from films to about 12 inches in width. Seams tend to swell and die out, to be replaced by others on the same plane farther away or on a different level. When several are present one above the other within some feet of strata, as often happens, the compound body of rock and fibre is termed a " reef," and may be worth extracting. Development is often better on or alongside a gentle or sharp anticline or within a fold. Corrugations and peculiar " cone structures " are common. A reef may be patchy or may persist for a mile or more. A handicap is the excessive hardness of the country-rock, and many of the workings are hence confined to outcrops and are shallow, though at depths of from 20 to 100 feet the silicified crust usually gives way to a softer limonitic leached zone with the fibre normally remaining unaffected. The mines are usually dry.

(i) *Crocidolite* or " Blue Asbestos " is a ferriferous amphibole with low alumina, lime, and magnesia, but with from 5-6 per cent. of soda. It is lavender to dark blue and silky in the best grades. It occurs in the Cape in the lower half of the Griquatown beds and is worked about Prieska and at intervals along the " Asbestos Mountains " to beyond Kuruman, the most important centre being Koegas on the Orange River. It is found in the Transvaal in a similar environment in the Malips River area, Pietersburg district, where it is mined in association with amosite. The fibre rarely exceeds 4 inches in length, but 1-1½ inches is regarded as good. Ribbon-rock with bands less than one-fifth of an inch is discarded. In places the mineral has been altered by oxidation to the soft, golden-yellow substance Griqualandite, or has been pseudomorphed in silica so that it still displays a fibrous structure. This golden-brown mineral, which has been much used for jewellery, is the substance to which the name " crocidolite " has erroneously been given.

The output of this valuable fibre was 33,659 tons in 1951.

(ii) *Amosite*, so named by Hall, is a slightly more ferriferous amphibole with more magnesia but less lime and alumina and no soda. It

is white to ashy grey. It is mined in the north-eastern corner of the Bushveld, mainly at Penge along the Olifants River and again in the Malips River area. The fibre attains an exceptional length—up to over a foot—but from 4-7 inches is regarded as good. In places there has been conversion to soft brittle " Golden Reef."

The output was 54,053 tons in 1951.

(iii) Fibrous *Anthophyllite* is mined under the name of "asbestic" from veins in ultrabasic rocks on Korea north of the Zoutpansberg.

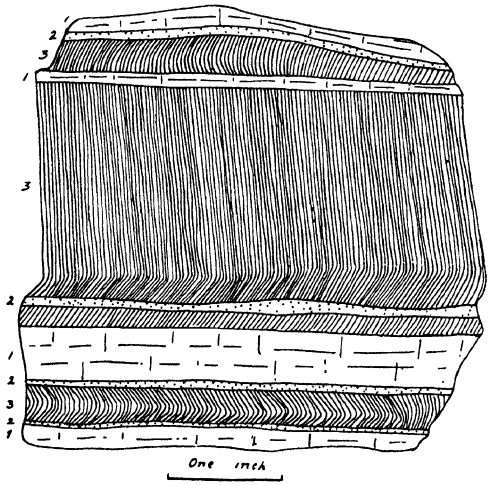

FIG. 70.—Crocidolite Rock, Daniels Kuil. 1, Jasper; 2, Black Ironstone; 3, Crocidolite asbestos. (*After* Hall.)

(*b*) *Slip-fibre Asbestos* or *Tremolite* is not uncommonly found in many parts of this country along planes of shear in altered basic rocks such as diabase and amphibolite, but being coarse-fibred and brittle is of small value.

Bauxite.—A high rainfall has been needed for the development of hydrated aluminium oxide. It is being mined on a small scale in Manicaland, on the Rhodesian border north of Penhalonga from a white clayey material containing some nodules of gibbsite, derived apparently from some feldspathic rock.

Big deposits, up to 50 feet thick and reddish, have been proved on the Mlanje Mountain, Nyasaland, resting on and formed from alkali syenite.

Building and Ornamental Stones.[1]—The demand for these is naturally greatest in the immediate vicinity of the towns; but, since the cost of transport from any distance may be high, local material has generally to be employed and the selection is hence often limited. Indeed, certain towns such as Lourenço Marques and Beira are some distance from suitable stone. A lot would obviously depend upon the character of the building and whether the work is of a high or low grade. Whereas stone for the exteriors of public buildings, for interiors, for fine work or decoration, could sustain moderate freight charges, that intended for foundation work, bridges, etc., would generally have to be quarried from the least inferior stuff near at hand.

South Africa is certainly well supplied with granites and other classes of rough stone, but the higher qualities of freestone are rarely conveniently situated. Furthermore, European towns can show buildings centuries old in which the behaviour of various stones under exposure can be studied, whereas in this land this is not the case; consequently the durability of any particular variety is more or less unknown, a difficulty increased by a general reluctance to quarry deep down into perfectly fresh rock.

Of the *granites* a grey, biotite type is quarried at Paarl and near Capetown, a flesh-coloured kind at Parys and Johannesburg, a reddish one at Umzinto south of Durban, and grey hornblendic varieties at Bulawayo and Salisbury. In some granites the porphyritic feldspars are too large, or the rock is too streaky or foliated, or is disfigured by dark micaceous or hornblendic patches. The dark red Bushveld granite could be employed much more frequently than it is, but there is a preference for the speckled grey norite, quarried north of Pretoria, which rifts well along its faint "stratification." The pinkish nepheline syenite of the dyke at Bank Station and the red syenite from Leeuwfontein have been used to a moderate extent in Johannesburg. Diabase and dolerite are decidedly hard to trim and unpleasingly dark in appearance and are consequently only used for foundations or rough work. It is curious that so little attention should have been paid to the various porphyries, since they occur in so many shades of colour—green, yellow, reddish, and purple—and owing to their feldspar phenocrysts often make handsome rocks.

Metamorphic *limestones* in various tints, often foliated and carrying serpentinous bands or contact minerals, abound in South-West Africa, as at Karibib—whence a high-grade marble was formerly exported—or Chisawasha near Salisbury. Red varieties are being quarried on Kairo in the western Zoutpansberg, and excellent white and fancy marbles at Marble Hall on the Olifants River south of the Springbok

[1] For details see:—A. E. V. Zealley, *Ninth Ann. Rep. Rhod. Mus.*, 1910, 53-60; P. A. Wagner, *Union S.A.G.S.*, Mem. 7, 1916, 109; T. G. Trevor, *S.A.J.I.*, 1919, ii, 634; W. Wybergh, *Union S.A.G.S.*, Mem. 20, 1932.

Flats, and near Hol River Station in Van Rhynsdorp. The various bedded dolomites have seldom been employed, mainly because of their dark colour and cherty bands, while the many quartzite formations are not in demand, because of their hardness. A unique valuable dark-grey material containing pyrophyllite, known as " Wonderstone," seemingly an altered volcanic ash, is extracted near Ottosdal in the western Transvaal. It is soft, easily turned, singularly resistant to acids and a good electrical insulator. The white or greyish Table Mountain sandstone of the Cape Peninsula and its reddish equivalent in Natal and Zululand are much used, though the diagonal bedding sometimes proves objectionable, but in the south of the Cape the rock is hard and often sheared, *e.g.* at Port Elizabeth.

The Karroo System provides the bulk of the *sandstones* and *free-stones*. The grits of the Coal Measures of northern Natal, the south-eastern and southern Transvaal, those of the Beaufort of Kroonstad and Queenstown, of the Molteno Series everywhere, and of the beds at Wankie in Rhodesia are extensively quarried, the rocks being generally whitish to greyish with angular interlocking grains of quartz and some feldspar. At Balmoral east of Pretoria the rock has concretionary marcasite, which readily decomposes, causing staining and disintegration. The finer-grained sandstones are feldspathic, buff, or yellowish-green in the case of the Beaufort, grey in the case of the Molteno ; they are often of good quality. The Cave-Bushveld-Forest Sandstone is everywhere a good freestone, largely unbedded, with even-sized grains and ranging from cream to terra-cotta—occasionally dark red, as near Warmbaths, Transvaal, where it furnishes a good stone ; it is quarried at Pasipas north of Bulawayo. The very porous and the laminated kinds and those carrying opal as the cement have to be avoided.

The Uitenhage Series furnishes good buff freestone at Oudtshoorn and white at Mossel Bay. The Tertiary limestone of the Alexandria Formation has been employed at Bathurst, while several large buildings in Cape Town have been constructed of the rather similar recent sandy limestone of Saldanha Bay, which is very soft to quarry, but hardens on exposure ; the material does not, however, stand up at all well to the weather. Beautiful " onyx-marble " is extracted from a travertine deposit near Port St Johns.

The thinner-bedded sandstones of the Karroo System are used for kerbing, pavements, etc., while those of the Fish River Series in South-West Africa produce fine slabs. The Pretoria beds furnish excellent flagstones and roofing slates, as at Pretoria and Mazista on the Zeerust railway ; also, though not so good, there are the Malmesbury beds of the Cape.

Chromium.—Bodies of chrome-iron ore or chromite occur as segregations in ultrabasic rocks of two different ages in Rhodesia and

the Transvaal, the former country having produced in 1951 330,989 tons—and altogether 6,925,663 tons valued at £16,713,432—the latter 600,767 tons in 1951.

A. *Rhodesia.*—(1) In silicified serpentine, talc schist, and talc-carbonate schists as small crystals which become aggregated to form veins and lenses, either singly or in groups. The curved belt at Selukwe contains numerous valuable bodies that are actively being mined by open cuts, *e.g.* at the Chrome Mine, Black Rocks, Selukwe, etc., and at Mashaba. As it contains alumina and magnesia, the ore appears to be mostly chrome-picotite; much of it runs to about 50 per cent. of chromium sesquioxide.[1]

(2) Along the Great Dyke,[2] as seams averaging 7 inches thick in serpentinised hartzburgite dipping inwards at moderate angles (Fig. 30), mined in shallow workings essentially where the railways cross that intrusion, *i.e.* at Lalapanzi, Makwiro, and Darwendale, the product averaging between 50 and 53 per cent. of Cr_2O_3.

B. *Bushveld Region.*[3]—Chrome ore occurs over a wide area and in immense amounts, though mainly in Lydenburg and Rustenburg, within a zone of the Lopolith marked by pyroxenites rich in bronzite, which is some thousands of feet above the base of the complex (Fig. 22). Two horizons are represented in the eastern region and three in the western. All gradations are found from disseminations to solid lenses and seams up to several feet in thickness, which conform strictly to the pseudo-stratification of the enclosing rocks and hence dip at low or moderate angles as on the Dwars River (Fig. 71); they tend to be associated with segregations of anorthosite, especially in the west.

It is deduced that they have originated in the magma by the settling down under the influence of gravity of early-formed, heavy crystals of chromite and chrome-picotite, thus producing rocks composed principally of those minerals, but with subordinate amounts of bronzite and plagioclase.[4] The chromitite carries from 35 to 50 per cent. of chromium sesquioxide, but the seams mined do not generally contain more than 43 per cent., though the grade can be appreciably raised by washing. Production has mainly been from the Steelpoort Valley, Lydenburg (Mooihoek, Tweefontein, Grootboom), and from Rustenburg (Swartkop near Chromedale Station in the north, and near Boshoek Station in the south).

[1] A. E. V. Zealley, *S. Rhod. G.S.*, Mem. 3, 1919; *T.G.S.S.A.*, 1914, xvii, 60; A. M. Macgregor, *S. Rhod. G.S.*, 1947, Bull. 38, 10.

[2] F. E. Keep, *S. Rhod. G.S.*, 1930, Bull. 16; B. Lightfoot, *P.G.S.S.A.*, 1941, xliii, p. xxxvii.

[3] P. A. Wagner, *S.A.J.S.*, 1923, xx, 223, where previous literature is cited; E. Sampson, *Econ. Geol.*, 1932, xxvii, 113; W. Kupferburger *et al.*, *Union S.A.G.S.*, 1937, Bull. 10.

[4] C. F. van der Walt, *T.G.S.S.A.*, 1942, xliv, 79.

Clays.[1]—Brick-earths are available near most centres, good products being turned out at each town, but clays fitted for fire-bricks, tiles, etc., in convenient situations, are indeed few. They fall into several classes :—

(*a*) *Kaolinitic types*, with 60-70 per cent. of silica, not highly plastic, those derived from granite being low in titania. A good example is those at Grahamstown, where deep weathering of the Dwyka tillite and Lower Shales has occurred beneath silcrete. Those

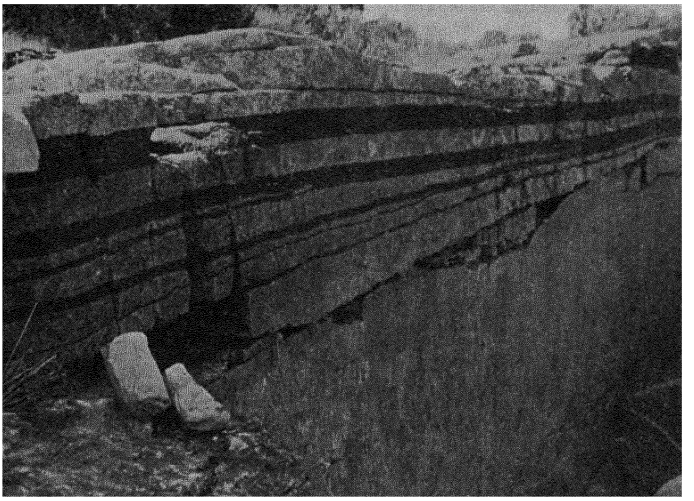

FIG. 71.—Black chromitite seams in pale spotted anorthosite, Dwarsrivier gorge, Lydenburg. (*Photo.* C. A. Hide.)

derived from slates carry normally some iron and titania, as at Pretoria, Stellenbosch, and Cape Town.

(*b*) *Marine types*, with 60-65 per cent. of silica and not only kaolinite but some montmorillonite and probably illite. These are extensively worked near Port Elizabeth where, derived from the Uitenhage beds, they are red, yellow, or greenish with some gypsum locally. Here, too, may be placed those of the Cape Flats.

(*c*) *Fireclays*, with 40-50 per cent. of silica and composed of kaolinite and finely divided quartz and muscovite with varying amounts

[1] V. L. Bosazza, *Min. Research Lab. Univ. Wit.*, 1940, Bulls. 3 and 5; *S.A.J.S.*, 1942, xxxviii, 145; 1943, xl, 109; 1945, xli, 161. Also "The Petrography and Petrology of South African Clays," (unpublished) monograph.

of organic matter, while in places carrying a little iron in their upper part. Ranging from massive non-plastic to plastic kinds, they are worked at Wankie in Rhodesia though predominantly on the Rand, as at Olifantsfontein, Boksburg, Brakpan, Springs, West Rand, and Lawley, overlying the Dwyka conglomerate, in sink-holes in the Dolomite, or intercalated in the Coal Measures towards the east. Excellent fire-bricks, pots, pipes, and finer wares are being manufactured from these large deposits.

Coal.[1]—Workable seams, everywhere *lying almost horizontal*, occur in each of the three divisions of the Karroo System above that of the Dwyka, though it is noteworthy that no coal of any importance has been discovered west of the twenty-sixth meridian.

The Middle Division of the Ecca Series—known indeed as the " Coal Measures "—contains a number of seams, which are of surprising thickness in places, and in truth furnishes almost the entire output; the Beaufort seams are chiefly known along the inner side of the Lebombo, while the Stormberg seams are practically restricted to the Stormberg-East Griqualand region. In association with the first and last are seams of torbanite (" oil-shale ") (see p. 534).

A. *The Ecca Seams.*—In the south a thickness of from 150 to 300 feet in the middle of the Coal Measures alone carries workable coal, but the gradually increasing overlap at the base of the Ecca Series on proceeding northwards has caused the lower strata to die out progressively in that direction against ridges of the ancient floor, and with them the lower and then the higher seams. Concurrently as one proceeds northwards coals progressively appear on higher horizons—at the top of the Middle Ecca in the Springbok Flats, at the base of the Upper Ecca in the northern Waterberg and the Zoutpansberg and well within the Upper Ecca in Southern Rhodesia. This parallels the progressive rise of the seams of the Carboniferous in Great Britain into higher zones when followed from north to south.

[1] For further details the following should be consulted :—

Min. Resources Union S.A., 1940, 358-400.

C. J. Gray (Natal and Zululand), *P.G.S.S.A.*, 1924, xxvi, p. xix.

E. T. Mellor, *Geology Transvaal Coal Measures*, G.S. Tvl., Mem. 3, 1906. Recent additions to our knowledge, etc., *T.G.S.S.A.*, 1922, xxv, 1.

South African Mining Journal, Special Coal Numbers, December 1919 and July 1921. Special Rhod. Moçamb. Congo Number, December 1920.

F. A. Steart (Natal), *T.G.S.S.A.*, 1919, xxii, 90.

W. Wybergh, *The Coal Resources of the Union, Union S.A.G.S.*, Mem. 19, 1922, i; 1925, ii; 1928, iii.

B. Lightfoot, *Wankie Coalfield*, S. Rhod. G.S., 1914, Bull. 4; 1929, Bull. 15.

Report Rhodesia Resources Committee (Coal), 1921, 134-141.

A. C. Graham and P. N. Lategan, *The Coals of the Witbank District*, 1931.

Union S.A.G.S., 1940, Coal Survey: Mem. 1.

Although some thin coals are known to the south of Greytown, the coalfields of the Union really commence at Elandslaagte, north of Ladysmith. From this point northwards through Dundee, Newcastle, Utrecht, Vryheid, Ermelo, and Carolina, then westwards through Witbank to Springs, and thence southwards into the Orange Free State there extends a coalfield with truly enormous reserves. Its importance can be gauged from the fact that the Union's annual output has exceeded 29 million tons, of which the Transvaal has contributed over 70 per cent.; that of Southern Rhodesia was 2,535,449 in 1951.

That the seams would be regular across any particular field is hardly to be expected, yet individual coals are now known to persist over long distances, for research has disproved the old view that they are merely lenticular deposits of limited areal development.

Unlike the Carboniferous fields of the Northern Hemisphere the number of superimposed workable seams is few—four or five at the most—though rarely are more than two being worked in the same colliery, generally one and frequently merely its best portion; enormous quantities of low-grade coal are therefore being abandoned unmined. In Natal and the south-eastern Transvaal the average value of a seam is from 4 to 6 feet, but to the north-west, at Vereeniging, Springs, Witbank, north-western Waterberg, and Wankie some extremely thick coals are found, though such bodies invariably include much fuel of a low grade interlaminated with shale. The best quality comes from Natal, where the coals are generally bright and bituminous in contrast to the thicker though duller Transvaal coals. In Natal there is, however, much intrusive dolerite; indeed, Steart estimates that about three-fourths of the area known to contain coal has been affected for the most part, though not always, detrimentally. The central and northern areas on the contrary have only occasionally been thus invaded.

DISTRIBUTION.—*Natal.*—(*a*) *The Klip River Field* centres around Glencoe Junction and stretches from Elandslaagte in the south to Newcastle and Utrecht in the north. There are generally only two seams of importance, well up in the Coal Measures, the Bottom 5-7 feet thick—including coking coal and some gas coal—and the Upper 2-6 feet thick, though rather pyritic. Due to their depth and the action of intrusive rock the workings are liable to be gassy.

(*b*) *The Vryheid-Paulpietersburg Field* is particularly favourable for mining as the coal-zone, 100-200 feet thick, runs along the scarped sides of the Hlobane, Enyati, and Dumbe mountains. Four out of five seams are commonly workable; in upward order they are the Coking which, although rarely 2 feet thick, is mined because of its excellent qualities; the Dundas up to 8 feet wide; the persistent Gus 3-4 feet

with 10-13 per cent. of ash, valuable for coke-making, and the Alfred 1-8 feet.

Throughout Natal dolerite sills and dykes have caused dislocations, while in the Umlalazi Field near Empangeni in Zululand, where the seams reach up to 8 feet, the strata are broken and tilted.

Transvaal.—(*a*) In the *Ermelo-Carolina Field* the middle of five seams, a bituminous steam-coal, 5-6 feet thick, is mined. Another seam is associated with the torbanite exploited on Mooifontein (p. 535).

The Lowveld can show some thin coals in the vicinity of Komati Poort, the extension of which is known in Swaziland, though no mining is done.

(*b*) *The Witbank Field* is the most important producer in the Union, yielding from collieries situated around and to the south of Witbank and along the railway to Kendal nearly one-half of the total output. The Coal Measures, up to 200 feet thick hereabouts, lie horizontally on Dwyka conglomerate or on an uneven pre-Karroo surface and include five seams, the bulk mined being good steam coal. Faulting is rare. The Bottom or No. 1 Seam rests on or only a few feet above the Dwyka conglomerate—from which it may have derived boulders—and is a tough bituminous coal up to 11 feet thick, though wanting in places owing to a rise in the floor, as at Witbank. The Main or No. 2 above is the chief and most extensive seam, averaging 19 feet thick, though increasing to 27 feet in certain collieries, but only the lower portion—6-12 feet—is mined, the upper being much interbedded with shale and high in ash. The basal 15 inches is rich in spores, rather cannel-like and used in part for gas-making, in part for coking. No. 3 is narrow, but No. 4 is 9-27 feet wide and produces a house coal. No. 5 averages 5 feet, is more restricted but produces some coke.

(*c*) Around *Springs* the coals are more irregular and usually poorer, the one on the Apex-Brakpan ranging from 20 to 25 feet, of which the lower half is workable. To the east at Welgedacht, Largo, etc., the lowest of three seams runs from 7 to 40 feet, the second from 17 to 45 feet; the lower part of the first alone is worked. Similarly, in the great coal-basin of the South Rand beyond Heidelberg with a main seam of no less than 53 feet inclusive of some sandstone and shale, only the lowest 7 feet, a good steam-coal, is extracted. At *Vereeniging* two seams occur close together, the lower 17 to 60 feet thick, of which 8½ feet is mined, the upper 40 feet. At *Clydesdale* in the Orange Free State the basal 9 feet are being mined out of a 32-ft. band, while at Vierfontein there is a 6 to 9-ft. seam. Far to the south two seams have been proved in a borehole at Kroonstad 1000-ft. deep. The many borings in the Odendaalsrus area have proved one, and sometimes more, seams ranging up to 12 feet thick, that appear to be widespread though of poor quality usually.

On the south, south-east, and north-west sides of the *Springbok Flats* the top seam passes upwards through alternations of coal and shale into the shales of the Upper Ecca, a feature more marked still in the *north-western Waterberg*,[1] where borings carried down in places to 1000 feet have proved a field some 20 miles wide that runs from the 28th parallel westwards across the Crocodile into Bechuanaland—where coal is known at Debeeti. This basin, much concealed by sand, is traversed by nearly east-west faults. There are two groups of seams, the lower associated with sandstones of Middle Ecca age, and inclined to become steam-coals; the upper interbedded with shales, assumed to be of Upper Ecca age, bituminous but high in ash (25-30 per cent.). On the farm Groot Geluk the two important seams were 13 and 22 feet thick, but in the 280 feet of overlying shaly strata no less than *113 feet or two-fifths* were coal, among which were bands up to 10 feet. This section is astounding, but other boreholes have confirmed such considerable though variable alternations within the upper group.

Along the north of the *Zoutpansberg* coals have been struck in boreholes, especially near Waterpoort Station.

Bechuanaland.—Borings have proved good coals at Debeeti Siding and to the south-west of Palapye Road, though more is needed to establish their persistence.

Rhodesia.—In the south lie the Umsingwani, Singwesi, and Massabi fields with one or more seams from 3-4 feet thick, as yet unworked, but the Sabi area more to the east has only one thin coal. Over the axis of Rhodesia the Coal Measures are absent but reappear to the north of Bulawayo, one or more seams from 2-9 feet thick being known in the Mafungabusi, Sengwe, Busi, and Lubu areas. At Lubimbi on the Lower Shangani River the coal is said to be thick and to have coking qualities.

In the important *Wankie Field* to the west there are three seams, of which only the basal one, resting on sandstone, is mined, giving a bituminous coal of exceptional quality as well as an excellent coke. From 6-12 feet thick at the Old Colliery it increases to nearly 40 feet in a westerly direction, and is 23 feet thick at the New Colliery (Fig. 47). The output well exceeds one and a half million tons annually, of which most is exported to the northern Copper Fields. The other Rhodesian coalfields are likely to remain untouched for many years owing to the vast resources and geographical advantages of Wankie.

Coal is also known to crop out farther down the *Zambezi Valley*, for example on its northern side along the Luano River near Zumbo, and again right down at Tete where, near the Muatize River, it is being mined.

[1] P. E. Hall, *Jnl. Chem. Met. Min. Soc.*, 1945, xlvi, 124. *Union S.A.G.S.*, 1945, Bull. 15; 1946, Bull. 16.

Characters of the Ecca Coals.—Semi-bituminous (steam) coals predominate in South Africa, bituminous kinds are much less common, while " gas " coals are rare. The bottom portion of the second seam in the Witbank area is of the last-mentioned character—a valuable band carrying about 38 per cent. of volatile matter, this being closely approached by some of the upper coals in the Waterberg, although they have a rather high ash-content. There is a strong tendency for a higher grade of coal to characterise the lower part of each seam, the upper not uncommonly containing ash-rich coal and shaly streaks and layers, though that may be offset to some extent by a higher proportion of volatile hydrocarbons. Valuable coking properties are displayed by those seams or portions of seams having a low carbon-hydrogen ratio in Natal, Vryheid, Witbank, and Wankie, the ash of the product ranging between 11 and 14 per cent. Anthracitic coals are unfortunately only too well represented in Natal; they show a higher percentage of ash than European anthracites, which leads to clinkering in the furnace. Calorific value and specific gravity are usually related linearly to ash-content. The minimum standard demanded for first-grade has been officially set at 12·8 lb. per lb. calorific value.

The average Natal coal shows a proximate analysis as follows :—Fixed carbon 68 per cent., volatile hydrocarbons 20 per cent., sulphur 1½ per cent., ash 10½ per cent. For the ultimate analysis an average Transvaal coal can be cited :—carbon 66 per cent., hydrogen 4½ per cent., nitrogen 1½ per cent., oxygen (by difference) 11½ per cent., sulphur 1½ per cent., moisture 2 per cent., ash 13 per cent. The sulphur in all the coals is always a bit high, often exceeding 2 per cent., mainly in the form of pyrite or marcasite, but partly in organic combination.[1] The nitrogen [2] content is considerable as compared with European coals, those in the Witbank-Springs area giving fairly uniform values ranging from 1·3 to 2 per cent.; in the Vryheid-Natal region over 2 per cent. has often been found—as much as 2·3 per cent. at Northfield Colliery, Glencoe. Such coals can be and are being utilised for the manufacture of by-products, the nitrogen being largely recovered in the form of sulphate of ammonia. The Wankie coal shows carbon 67 per cent., volatile matter 23½ per cent., moisture 10 per cent., and ash 8½ per cent. The Tete coal analyses show from 11 to 16 per cent. ash and 22 per cent. volatile matter.

B. *The Beaufort Seams.*—Characteristically thin and semi-anthracitic in their nature, such coals occur between Mooi River and Estcourt and near Bergville in Natal, between Volksrust and Wakkerstroom and also at Senekal, while the upper coals along the inner side of the

[1] J. Gray, *J.S.A. Chem. Inst.*, 1922, v, 12; P. E. Hall, *Journ. Chem. Met. Min. Soc.*, 1930, xxx, 195; G. A. Smith, *ibid.*, 1941, xlii, 1.

[2] V. Bosman and S. W. Parr, *S.A.J.I.*, 1923, vii, 215.

Lebombo Range are probably on this horizon. They are exceptionally developed at Somkele in Zululand, where there are two seams 18 and 40 feet thick dipping at 30 degrees. Mining has been suspended because of their low proportion (about 7 per cent.) of volatile matter.

The so-called "*Fissure coals*" or "*Pseudo-anthracites*," known originally from the Nieuwveld escarpment and Camdeboo, are widely scattered in that area within beds ranging from the White Band to Lower Beaufort. Whether following the bedding or vertical jointing, as at Merweville, they are remarkable in cutting across and including fragments of the enclosing strata and—associated with calcite veins—they range from threads to bodies 7 feet thick though always variable.[1]

The material resembles anthracite in its brittle and shiny nature, low ash, and high fixed carbon, but is unique through containing some nickel and traces of boron and vanadium, also authigenic quartzes including specks of colloidal coal. It is clearly due to the polymerisation of ascending gaseous or liquid hydrocarbons derived either through distillation of coal or carbonaceous shale in depth by Karroo dolerite, or else from traces of petroleum. At Uithoek, Glencoe, such a vein of pseudo-anthracite cuts steeply across Ecca sandstone 100 feet above a coal seam that has been converted into semi-anthracite by a dolerite sill lower down.

C. *The Stormberg Seams.*—Coals are found on three horizons in the Molteno beds at numerous points in the Stormberg and beneath the Drakensberg but, through being lenticular in their nature, are rarely traceable through any long distance.

Mining has been restricted to two horizons, the lower at Indwe, the upper at Molteno, Cyfergat, and Bamboes Spruit in the Stormberg. The seams being composite, much shale has to be removed to recover a few feet of coal, the latter being high in ash (25 per cent. and over) and low in volatile matter (11 to 20 per cent.).

Extension of the Existing Coalfields.—It is curious that the known areas should lie between the twenty-sixth and thirty-third meridians. Within the Ecca Series coal can be anticipated wherever the "coal measure facies" has been properly developed but, as mentioned earlier, over a large section of the northern Transvaal and Southern Rhodesia that formation has never been deposited or else has been overlapped by the Stormberg Series. In a southerly direction coals are not yet known beyond the line drawn from Bothaville through Odendaalsrus, Kroonstad, and Ladysmith to Verulam; farther to the south and west there sets in a phase of sedimentation which is devoid of carbonaceous deposits, thus setting a limit to the area worth prospecting. This eliminates from consideration the whole of the Cape

[1] A. W. Rogers, *Ann. Rep. G.C. for* 1910, 25; P. A. Wagner, *S.A.J.I.*, 1918, i, 126.

Province, the bulk of South-West Africa, and possibly the western Kalahari; but detailed knowledge of much of these two northern regions is still lacking.

Similar considerations apply to the Beaufort Series, the "carboniferous facies" so far as is known being only developed, though poorly, in northern Natal and Zululand. The Stormberg coals are nowhere thick and it is unlikely that they can be better developed in the eastern Free State where the Molteno beds are thinning rapidly, while it is very doubtful whether the latter formation is present in the Transvaal; the seam at Vangheining in the Springbok Flats may perhaps come here.

The vast area to the east of the Lebombo is, so far as is known, composed of marine Cretaceous and Tertiary and, unless the Karroo sediments have been brought up again somewhere on the eastern side of this great monocline by flexuring or faulting, coals corresponding to those in the Union cannot be expected. The belt farther north following the Rhodesia-Moçambique boundary may just possibly contain seams in the section between the Limpopo and the (northern) Sabi, while coal will probably be discovered in the strip of Karroo beds on the western side of the Buzi sunklands.

Coal beneath the Central Karroo.—From the outcropping around the Karroo basin of the carbonaceous zone of the Upper Dwyka Shales, Dunn in 1886 propounded the theory of the probable existence of coal beneath the Karroo, a view which seemed to obtain support from the discovery of the seams at Vereeniging resting upon the glacial conglomerate. It is now known that owing to an overlap those coals are on a higher horizon; the basin-like form of the Karroo is, moreover, not original, but is largely subsequent, while the carbonaceous zone is wonderfully persistent, has a wide extension outside the area, and not improbably represents a group of black sulphuretted estuarine muds. Granted that this band did pass into coal with depth, the great thickness of its covering within the south and south-west of the Karroo would place it far beyond the limits of profitable mining.

Cobalt.—Safflorite (arsenide of cobalt) and cobaltite were formerly mined at two localities in the Middelburg district, Transvaal—on the Kruis River at or near the junction of altered Pretoria quartzite with a gabbro intrusion, and near Balmoral Station with actinolite and feldspar in what appear to be basic dykes in extremely altered flinty Pretoria beds. In both cases the mineralisation can probably be connected with the Bushveld Complex.

Copper.—Of widespread distribution, though too often in trivial amount, it is found within formations of several ages as :—

A. *Supposed Magmatic Segregations*—(1) *Namaqualand.*—So far back as 1685 the copper was discovered by Governor S. van der Stel

in the western part of the Koperberg close to the subsequent Carolusberg Mine. Mining began in 1852, and is proceeding actively to-day. Occupying a 15-mile-wide zone in the gneisses are some hundreds of intrusions trending east-north-east, irregularly dyke-like and all closely related, although ranging from hypersthenite through mica diorite and norite to anorthosite, in general order of their injection. Some have a tendency to bulge in the middle with a spear-point upwards and a pinching root. Certain of them carry bornite, chalcopyrite, pyrrhotite, and magnetite, the sulphides being disseminated within the intrusions, but sufficiently concentrated in places in irregular masses to warrant mining, more particularly in the bulging portions. The mines are set on four major parallel lines, from north to south :—Garracoup—Tweefontein; Nababeep—Concordia; O'Okiep—Narrap; Springbok—Carolusberg, within an area of some 220 sq. miles.

At Tweefontein three bornite-chalcopyrite bodies occur in mica diorite, swelling in depth. The Nababeep, which produces disseminated bornite in hypersthenite, is developed to 600 feet. The Old O'Okiep—the richest and most important in the past—gave bornite-chalcopyrite ore of high grade from a swelling in mica diorite down to 600 feet. In the East O'Okiep the chalcopyrite-pyrrhotite ore is concentrated in a bulge of feldspathic norite down to 480 feet. The Carolusberg West body consists of disseminated bornite and chalcopyrite in a flattish dyke of mica diorite down to 700 feet. During the past some remarkably rich ore was extracted, to the value of 21 million pounds, work ceasing in 1932. Reorganised in 1938 as the O'Okiep Copper Company, the properties have in the period April 1940 to June 1947 milled 4,429,000 tons of an approximate grade of 2·5 per cent. copper. The reserves are considerable.

A magmatic origin for the ores was suggested so far back as 1856 by A. Wyley, a view supported by Rogers,[1] who noted that the sulphides fill the spaces between the silicates—which are fresh and have sharp crystal-boundaries—or are included in them, by Tolman and Rodgers, and by Latsky [2] from a close mineragraphical study. Microscopical evidence has, nevertheless, disclosed appreciable minute fracturing of the silicates and widespread rock alteration with metasomatic replacement of not only noritic but country rock, and the tendency to-day is to regard these remarkable deposits as mainly of hydrothermal origin.[3] A pre-Nama age has been proved.

(2) *Insizwa* and *Vlakfontein.*—These copper-nickel ores are referred to under *Nickel.*

[1] A. W. Rogers, *Union S.A. Ann. Rep. G.S. for* 1912, 127; *P.G.S.S.A.*, 1916, xix, p. xxi.

[2] R. Latsky, *T.G.S.S.A.*, 1943, xlv, 109.

[3] From information kindly supplied by Dr P. G. Söhnge.

B. *Replacements and Veins.*—(1) *Messina, Transvaal.*[1] The presence of extensive ancient workings proves the antiquity of copper mining in this area. The three important mines—the Messina, Harper, and Campbell—are situated on a persistent line of fracturing and crushing in the old gneisses (including meta-quartzites and hornblende schists) that runs east-north-east to the Limpopo River and gives off successive branches more or less parallel thereto or in a general north-south direction within a zone 500-1500 feet wide. It is penetrated by a much altered and in places mineralised dolerite dyke.

The lodes consist of quartz veins that swell out into irregular bodies of considerable size, many of them developed from breccias produced by fracturing or volcanic explosion. An instance of the latter is the so-called " pipe " or " L Lode " in the Messina Mine that, starting from about 500 feet in depth, expands downwards and flattens towards the north-west. In this mine the important Bonanza group of veins is given off to the north, dipping south-eastwards, and the " K Lode " to the south, the workings having gone down to 2300 feet. In the Harper Mine the two principal lodes pitch south-westwards within a split in the main fault and also include curious mineralised breccias. It is 2200 feet deep. The Campbell to the west shows several parallel or oblique lodes that have been followed to 700 feet.

The annual production over the past few years has averaged about 12,000 tons of copper, the metal being of great purity. Numerous minor occurrences are known over a wide region. It is believed that the ore was brought in by heated solutions that have profoundly changed the country rock with the development of zoisite, prehnite, epidote, chlorite, sericite, talc, quartz, calcite, feldspar, zeolites, and sulphides. In the upper levels chalcocite dominates, while bornite and chalcopyrite appear deeper down, bornite becoming the chief copper-mineral. Söhnge has given good reasons for regarding this widespread, though apparently shallow-seated, mineralisation as of late Karroo age, connected with the post-basalt augite granophyre batholith situated to the north-east in Rhodesia (p. 311) and related to the strong faulting in this region.

(2) *Tsumeb, South-West Africa.*[2]—The ore-body is a variable lense of sandstone-like rock—previously mistaken for aplite—pinched in by overthrusting in steeply-dipping Otavi Dolomite, and proved down to 575 metres. Hydrothermal mineralisation has followed such contacts and largely replaced the dolomite. In the deeper levels the ore is exceptionally pure, though highly complex, consisting mainly of sulphides and arseno-sulphides such as chalcocite (derived from chalcopyrite), bornite, argentiferous galena and zinc blende. Many interesting

[1] P. G. Söhnge, *Union S.A.G.S.*, 1945, Mem. 40.
[2] *Union S.A.G.S.*, 1944, Mem. 39, 132.

minerals are present, often in perfectly-formed crystals, mainly compounds of copper, lead, and zinc, but also quite a number of rare minerals such as mottramite and germanite; in fact, the Tsumeb Mine has become celebrated in mineralogy for this reason.

Since 1907 the mine has produced much copper, lead, and silver, though little zinc, but the ores have proved difficult to treat. The reserves are estimated at a million tons with an average metal content of 10 per cent. copper, 18·5 lead and 10·5 zinc. In 1951 717 tons of cadmium were recovered.

(3) *Khan Mine* east of Swakopmund.—This is peculiar in that the copper-bearer is an inclined body 1100 feet long and up to 7 feet wide of coarse microcline pegmatite in gneiss that contains diopside, hornblende, calcite, and sphene. It has been brecciated and is veined by bornite—massive or disseminated—and some chalcocite, through hydrothermal action.

(4) Copper reefs are known in many other places in the primitive rocks and in diverse formations, though unpayable in many instances, as in the old Numees Mine in Namaqualand. In South-West Africa the old mines on Naob and Ubib near Usakos are being reopened. In the Sinclair Mine north of Aus copper occurs as chalcocite in a quartz vein in porphyry, in the Matchless Mine near Windhoek as cupriferous pyrite in biotite schist, and in the Areachap near Upington as cupriferous pyrite in quartz schist.

The Edmundian Mine in Manicaland, near Umtali, has chalcopyrite in serpentine, while the Umkondo in the Sabi Valley, Melsetter district, has nodules of bornite in a layer of shale in the Umkondo Series, possibly connected with intrusions.

In addition there are several gold mines which produce or have produced copper as a by-product, such as the Falcon, Umvuma, the Valley Mine at Gwanda in Rhodesia, the T.G.M.E. Mines at Pilgrims Rest, and the Mamre Mine at Carolina, Transvaal.

Corundum.[1]—Since 1912 the Transvaal has sprung into the position of the world's great producer of this valuable abrasive. For the five years 1942-6 the production was approximately 4500 tons per annum, valued at about £55,000, while 5030 tons were produced in 1951, sold for £94,701.

The fields cover three areas :—(1) a wide stretch south of Louis Trichardt running east-west for 100 miles, (2) one north of the Zoutpansberg, and (3) the southern margin of the Palabora granite near Leydsdorp. The corundum is found in pegmatitic and aplitic veins

[1] A. L. Hall, *Union S.A.G.S.*, Mem. 15, 1920; *S.A.J.I.*, 1924, vii, 801; W. Kupferburger, *Union S.A.G.S.*, Bull. 6, 1935; J. W. Brandt, *T.G.S.S.A.*, 1947, xlix, 51.

cutting masses of serpentine, peridotite, pyroxenite, and amphibolite, which have been invaded or enveloped by the dominating Older Granite and Gneiss. By reciprocal reaction with the ultrabasic walls and loss of silica to the latter the acid magma has become locally supersaturated with alumina, which has crystallised as corundum with either plagioclase (as plumasite rock) or margarite (as marundite rock), both types being nearly always coarse-grained. Following the habit of pegmatites the reefs are highly irregular in their distribution, development, and corundum-content. This mineral, which may even constitute from one-third to over one-half the weight of the rock, is present either as well-shaped pale greenish crystals often many inches in length or as more irregular masses in part replaced by silvery margarite and gibbsite through hydrothermal alteration. In places weathering of the formations has released masses of corundum rock or else corundum crystals, which are then found loose in the soil (eluvial). Both the mining and the recovery of the " reef " and the " eluvial " corundum are usually simple.

This mineral has also been found as barrel-shaped crystals in a micaceous gneiss at Steinkopf in Namaqualand. Marundite occurs in Rhodesia close to Selukwe as ruby-corundum with green margarite, while corundum has also been found as grey barrel-shaped crystals in mica schists together with much eluvial at Rusapi on the railway between Salisbury and Umtali, where it is being mined, and also at Marandellas.

Diamond.[1]—First made known from alluvial deposits, the gem was shortly afterwards discovered in kimberlite, and from the latter source has come the bulk of the production of the Union, which up to the end of 1938 is estimated at over 155,565,000 carats valued at £322,269,000 ; the output from South-West Africa has been quite considerable, but that from Rhodesia relatively insignificant.

While the alluvial stones have doubtless, as detailed below, been derived largely, if not almost entirely, from the wasting of kimberlite pipes, there are other diamondiferous formations which are of greater age than that phase of volcanicity. Indeed, the diamond has been discovered in (1) Witwatersrand (probably pre-Cambrian) beds, (2) late Karroo Sandstone (Upper Triassic), (3) Kimberlite pipes and fissures (Upper Cretaceous), (4) coastal deposits of South-West Africa (Eocene to Miocene), and (5) Gravels (late Tertiary or Quaternary). This, however, does not negative the possibility of its being represented within other of the well-known South African formations. Although

[1] The literature is voluminous, but the following should be consulted :— Gardner F. Williams, *The Diamond Mines of South Africa*, 2nd edition, 1906 ; P. A. Wagner, *The Diamond Fields of Southern Africa*, 1914, which contains a full bibliography ; and A. F. Williams, *The Genesis of the Diamond*, 1932, 2 vols., which is most comprehensive.

Harger's account of specimens, suggesting the Ventersdorp lavas as a source of the diamond, has received no support, his reference of certain stones to the Dwyka tillite at Klipdam in Barkly West [1] would seem worthy of serious consideration in view of the ascription recently of the diamonds in western Brazil and Bolivia to the Carboniferous glacials there. The stones found in the glacial drift of North America constitute indeed a parallel.

(1) *Witwatersrand Beds.*[2]—Numerous small stones were formerly obtained from the Gold Estates Reef, while latterly many have been recovered from the mortar-boxes of the Modder B and other gold mines. They are invariably small and of a light or dark green colour, apparently the result of radio-activity. There can be no doubt that they are of *detrital* origin and have been derived from pre-Witwatersrand formations, presumably situated to the north. They recall the similar occurrences of the gem in the Upper Vindhyan conglomerates of India and in the perhaps equally ancient quartzites of Bahia and Minas Geraes in Brazil.

(2) *The Triassic Deposits of Somabula.*[3]—At Willoughby Siding near Gwelo diamonds were found in a series of deposits believed to be of Tertiary or later age, and the gems were supposed to have originated from the denudation of pipes of kimberlite, such as are indeed represented in the neighbourhood and are known furthermore to be diamondiferous in some cases. More detailed investigations by Zealley and Macgregor have shown that these beds, which are resting directly on the granite, actually belong to the uppermost division of the Karroo System, as proved by their fossils. The gritty and conglomeratic layers contain many minerals such as are typically derived from the waste of crystalline and metamorphic rocks. Chief of these are staurolite, cyanite, tourmaline, garnet, corundum (including ruby and sapphire), zircon, topaz, chrysoberyl, and the diamond. The topaz is sometimes a beautiful pale blue, the chrysoberyl a greenish yellow, and the garnet a deep red colour, so that the concentrates from the workings have a striking appearance. Remarkable are "beans" of the mineral gorceixite, a phosphate of cerium and other rare elements, found in the alluvials of Gold Coast and Brazil. The diamond possesses a distinct greenish tint which is, however, lost during cutting, a feature which recalls the specimens obtained from the Witwatersrand beds.

While the evidence is so far all in favour of the precious mineral having been derived from the crystalline complex, apparently from a northerly source, the possibility is not excluded of its having origin-

[1] H. S. Harger, *T.G.S.S.A.*, 1909, xii, 139.

[2] See R. B. Young, *The Banket*, 1917, 37; J. G. Lawn, *P.G.S.S.A.*, 1925, xxvii, p. xxviii.

[3] *S. Rhod. G.S.*, Bull. 8, 1921.

ated in pipes, though of a different character and earlier age to those containing kimberlite, as the remarkable diamond pipe at Bôa Vista in Minas Gerais (Geraes), Brazil, would seem to indicate. It is interesting to note that the diamond is alleged to occur in the conglomerates of the equivalent Lubilash Series of the Congo and Angola.

In view of the above discoveries the assertion by Schwarz [1] of diamonds in the Molteno beds requires consideration, though the facts recorded do not negative the possibility that the minute splinters described by him were fragments of colourless garnet, a common constituent of the sandstones.

(3) *Kimberlite.*—Out of the scores of pipes known (see Chapter XVI) only about twenty-five have been extensively worked, the most important being :—(*a*) Cape—the Kimberley group, Smith near Barkly West, Leicester at Klipdam, Peiser near Griquatown, West End at Postmasburg ; (*b*) Free State—Jagersfontein, Koffiefontein, Roberts Victor and New Elands near Boshof, and Crown (or Lace) near Kroonstad ; (*c*) Transvaal—the enormous Premier ; while a number of smaller mines were temporarily exploited. Rich fissures were or are mined near Theunissen, Zwartruggens (Rustenburg), and Smith Mine. Of the operating mines the Premier makes an oval 2900 feet long and is opencast to 600 feet ; Bultfontein is mined to 1550 feet ; Dutoitspan —a twin pipe on a broad unpayable fissure—is down to 1350 feet, these three averaging 16, 28-29, and 13-14 carats per 100 loads respectively, while Jagersfontein has restarted.

In so minute a quantity is the gem present that only by the merest chance is it observed *in situ.* This will be better appreciated by stating that in a " ten carat " mine—quite a good proposition—the richness would be equivalent to 2 grammes per hundred loads, each of 1600 lb., or less than *one-twenty-two thousandths of 1 per cent.*

An extraordinary feature is the difference in the characters of the diamonds from different mines and even from separate parts of the same pipe, the individuality being so marked as to enable experts to identify the respective sources of representative parcels. Jagersfontein is conspicuous for the high proportion of cleavage fragments, Dutoitspan for its large yellows, Koffiefontein for a goodly proportion of pure white stones, the Voorspoed for its dull stones hard to cut, etc. ; but the distinctions are of course largely based upon a number of rather subtle differences. Further, there can be recognised diamond " provinces," one, for example, being the north-eastern part of the Orange Free State, with the stones found therein bearing a common stamp. Another point of interest is that, excluding the superficial portions of the pipes, mining has almost always proved a falling off in yield with depth, which cannot be entirely ascribed to the more

[1] *T.G.S.S.A.*, 1916, xix, 33, and discussion.

intractable nature of the " blue " with consequent non-recovery of the smallest gems.

The diamond occurs as well-formed crystals, broken crystals, and cleavage fragments along with some bort usually. In size the gems range from microscopic crystals to individuals hundreds of carats in weight, up to the immense Cullinan Diamond which, while scaling 3025½ carats or 1·37 lb. avoirdupois, was only the major cleavage portion of a huge octahedral stone. Quite a few of the stones have been found broken.

The crystals are generally octahedral with faces that frequently show microscopic pittings and sometimes etchings, while the edges are not uncommonly either bevelled by curved surfaces or replaced by striations and flutings. Dodecahedral crystals are also found and twinned forms (macles), occasionally the more globular, roughened and tougher kind known as " bort " or " boart," valuable for industrial purposes ; the real opaque carbonado is all but unknown, though the Premier Mine furnishes another curious black variety. True blue-white stones are not too common, and yellowish, brownish, and smoky tints are all too frequent, but many yellowish stones cut white.

(4) *The Inland Alluvial Fields of the Union.*[1]—The diamondiferous gravels are largely confined to the basins of the Vaal River and some of its tributaries, from near Standerton down to its junction with the Orange and beyond, though the gem has also been found at isolated points along the latter so far up as Aliwal North. Isolated patches occur on the Kaap Plateau, the Limpopo Valley to the north-west of Messina, and elsewhere.

They can be divided into (*a*) high-level gravels, standing hundreds of feet above the river channels (about 400 feet at Klipdam, Barkly West), or many miles distant therefrom (as in the area between Schweizer Renecke and Bloemhof), (*b*) terraces bordering the existing rivers at lower elevations than (*a*), (*c*) old gravel-filled channels or " deep placers," and (*d*) gravels within the present river-beds, which are exploited by means of " breakwaters." The oldest of these deposits probably dates back well into the Tertiary.

Remarkable are the rich fields of the plateau-region of Lichtenburg and Ventersdorp, where the gravels have subsided during and after their deposition into solution-hollows in the supporting Dolomite and may descend 50, 100 or even more feet below the present surface. The deposits form patches or well-defined " runs " and consist essentially of angular to subangular lumps of chert with a variable proportion of worn and transported pebbles of quartzite, jasper, agate, etc., set in a

[1] A. L. du Toit, *Ann. Rep. G.C. for* 1906, 171-76; *Union S.A.G.S.*, Expln. Sheet 53, Ventersdorp, 1935; A. F. Willams, *The Genesis of the Diamond*, 1932, i, chap. xviii.

reddish clayey matrix (Fig. 72). Vast outputs of diamonds have been obtained at Grasfontein, Bakers, Welverdiend, Goedgedacht, etc., for which the extraordinary rich "pot-holes" have largely been responsible. Individual returns have varied enormously from time to time as fields were worked out. Goedvooruitzicht between Lichtenburg and Ventersdorp has been leading producer.

The inclusions in the various gravels are mostly of the hardest rocks outcropping in the catchment, but may locally include boulders of all sizes derived from the Dwyka conglomerate. At certain points—for example along the Orange River in the Hopetown district, or on the Kaap Plateau—the pebbles have been cemented by carbonate of lime and converted into an intractable rock. There are present in the concentrates fragments and grains of heavy substances, such as banded

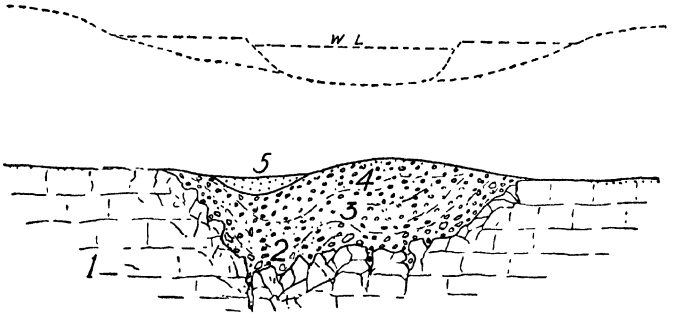

FIG. 72.—Generalised Section through a Lichtenburg Diamondiferous "Gravel Run," showing in dotted lines above the relative position of the original stream bed with its gravel terraces, since lowered into the Dolomite by solution. 1, Dolomite; 2, Bottom productive layer; 3, Middle poorer layer; 4, Top productive layer; 5, Soil.

ironstones or quartz-garnet rocks—termed "bantams" or "bandoms" by the diggers and regarded by them as indicators for the diamond; occasionally corundum, pyrope-garnet, and ilmenite are also found. At the Seta Mine on the Limpopo the gravels contain pebbles of corundum and the so-called "jade" from the Bushveld.

The yields, as can well be expected, are very erratic, but some rich pockets are occasionally discovered, particularly on the Dolomite area. Among the finds, which are generally of small or moderate size, have been some of several hundreds of carats in weight. While most of the stones are sharp-edged and brilliant, a limited proportion show abrasion of the corners and edges, which points to attrition; probably for this reason cracked stones are not common.

There has been much discussion regarding the source of the gems, for their characters and higher quality enable them to be distinguished

even in small lots from "mine stones." Increased acquaintance with the diamonds from the different diggings and from the numerous kimberlite occurrences has, however, shown that in not a few instances certain stones found in the gravels can definitely be matched with those furnished by pipes and fissures in the neighbourhood. It has not to be overlooked too that within this extensive region there must be a multitude of kimberlite bodies, as yet undiscovered, which could have contributed their quota.

Much evidence bearing upon this question has been brought together by Wagner,[1] which collectively goes to show that the bulk of the gems must have been derived from the waste of the kimberlite occurrences, known and unknown, though probably not all, for some may have been contributed by the older formations; indeed, certain green diamonds in the gravels near Klerksdorp are very like those known from the Witwatersrand bankets of that locality.

(5) *Coastal Deposits—South-West Africa and Namaqualand.*[2]—(*a*) Amazing it is to read the accounts of the discovery in 1908 of diamonds sparkling amid the sandy wastes of the Lüderitz coast and of the development within a few years of a huge industry in this arid inhospitable region.

The original discoveries were confined to a belt extending back from the coast not more than 15 miles, from Chameis to Lüderitz with smaller patches about Conception Bay and Sylvia Hill as well as certain of the islands off the mainland. They consist of two distinct types—(1) marine sandstones, grits, and conglomerates (p. 435) of early Tertiary age or younger, rising up to 500 feet above sea-level, and (2) alluvial and eluvial accumulations, over undulating rock surfaces, of coarse sands, largely derived from the disintegration of (1) and much fine wind-drifted sand, characteristically carrying chalcedony and banded agate. The latter forms the bulk of the material worked at Pomona, Kolmans Kop, Bogenfels, etc. The diamond content varies enormously. Where the stuff has been worked over by the wind, the precious contents have often become concentrated into surface patches, occasionally of astounding richness, so that they could be picked out by hand. The stones are of small size—five to eight to the carat generally, though some much larger ones have also been found; they are, however, of excellent quality.

(*b*) Since then, right along the Atlantic from Angola to the Cape, another type was found, much covered by drift sand, in the shape of relics of *wave-cut terraces* at heights ranging from 15 to over 200 feet above sea-level, carrying marine shingles with shells (*Ostrea*, etc.), each

[1] P. A. Wagner, *The Diamond Fields of Southern Africa*, 1914, 249-83.

[2] The literature on the fields is extensive, but the best account is given by Wagner (*loc. cit.*), who discusses fully the various hypotheses propounded.

normally overlain by sandy soil containing snail-shells and tufa. They mark out intermittent stages in the uplift of the land. At wide intervals between the Cunene and the Olifants rivers portions of such shingles have yielded diamonds—in places in astonishing amounts.

In the extreme north recent prospecting has disclosed local enrichments from Cape Frio southwards, the stones being small. From Oranjemund on the Orange River trenching in a dreary sand-waste has proved the northward extension for many miles of from one to three beaches standing at between 20 and 40 feet and from 40 to 300 feet wide which are being extensively exploited by Consolidated Diamonds. In the north these shingles rest on phyllites, but near the Orange River on sands and gravels.

(*c*) At Alexander Bay just south of the Orange River, in the State Alluvial Diggings, the celebrated, though narrow, shingles of the "Oyster Line" standing at 110-120 feet have over a stretch of some two miles produced a wealth of large stones.[1] Favourable positions for the gems are just beneath the larger boulders amid grit and broken shells. The overlying sands are in places calcified. Farther south are deposits at Buchuberg and The Cliffs.

(*d*) The widespread workings on Kleinsee at the mouth of the Buffels River reach up to 210 feet and include gravels and grits overlain by banded clays and sands without shells. Instructive are partly-worn blocks of silcrete from an adjacent capping on the gneiss. Rich alluvials occur some miles up that river at Grace's Puts, Nuttabooi, etc. Diamonds are known here and there in the coastal belt so far south at least as Strandfontein just south of the Olifants River.

Remarkable is the great amount of wear shown by many of the diamonds, certain of them resembling frosted glass marbles, while others show "percussion marks," these being due to their mutual impact and grinding by wave action on the beach. The average quality and price are unusually high. From the Orange River there is a decrease in mean size both north and south along the coast, which has suggested that the diamonds have largely been brought down by the Orange from kimberlite sources in the interior. The lengthy distance within which the gems have been found—950 miles—together with the presence of diamonds up the Buffels Valley, hints, however, at other sources as well.

Fluorspar or Fluorite.[2]—This mineral is widely scattered, but mainly connected with the Bushveld Complex and the Alkaline Rocks. Up to 1936 it was mined mainly from deposits in the Dolomite of the western Transvaal, such as Oog van Malmanie, Buffelshoek, and

[1] P. A. Wagner and H. Merensky, *T.G.S.S.A.*, 1928, xxxi, 1; A. F. Williams, *loc. cit.*, chap. xviii.

[2] *Union S.A.G.S.*, 1943, Bull. 14.

Witkop, where the reserves are still large, but later from veins and irregular bodies in the Red Granite of the Waterberg and Potgietersrust districts, such as at Ruigtepoort and Slipfontein. Production has usually been a few thousand tons a year.

Gem Stones.—Of precious stones other than the diamond, beryl in the form of aquamarine, heliodore, etc., occurs along with rose quartz in pegmatites which have been worked near Rossing Station east of Swakopmund, while strongly pleochroic cordierite (iolite) is obtained near Walvis. Beryl has been mined on a limited scale in the Steinkopf Reserve, Namaqualand, while crystals of emerald are extracted from schists near Gravelotte in the eastern Transvaal. The golden-brown " crocidolite " of commerce—" tiger's eye "—is derived mainly from the farm Naauwpoort in the Hay district. The beautiful green variety of serpentine cut under the name of " verdite " is mined in Barberton and the green, excessively hard variety of garnet incorrectly called " jade " in Rustenberg. The Somabula Field furnishes yellow chrysoberyl and pale blue topaz, while pink tourmaline (rubellite) is known from the Melsetter district. The garnets of kimberlite are sometimes cut under the name of " Cape rubies," but the bulk of the gems so called is of foreign origin. Agate is abundant, while spinel is represented at a number of places. All the opal found has been of inferior quality.

Gold.—Outstanding in South Africa is its enormous output of gold, while the multitude of ancient workings in Rhodesia testify to the importance of this country as a gold producer through the past centuries. The yield from the Union of South Africa to the end of 1951 has been 502,424,498 fine oz., and that from Southern Rhodesia 31,348,833 oz., while a small output comes from the Rehoboth and Omaruru districts, South-West Africa, and from Portuguese East Africa.

As pointed out earlier, the dominant period of mineralisation in this continent dates to the intrusion of the " Archæan " granites; admitting the theory of the placer origin of the Rand bankets, the gold in the latter would have been derived from the waste of these basement rocks and of their auriferous veins, otherwise another great period of auriferous impregnation must be postulated.

The deposits can be classified under two main heads :—

A. VEINS, B. CONGLOMERATES—the former of which can be sub-divided into (1) *Fissure Veins*, (2) *Bedded Veins*, and (3) *Replacements*.

A. VEINS. (1) *Fissure Veins*.—Characteristically possessing well-defined walls, they have either cut across the formation or, as is almost the rule in Barberton, followed the steeply dipping planes of bedding or foliation. They traverse alike the gneisses, felsites, schists, banded

ironstones and other sediments, but are especially common in the granite areas, generally in their marginal portions. White quartz is typical in these veins, less commonly quartz, calcite, and dolomite as in the Murchison Range, sometimes chlorite. The gold is irregularly distributed and mostly visible; pyrite may be present, sometimes arsenopyrite (Barberton, Gatooma), occasionally antimonite (Leydsdorp). While this class is well represented numerically it has not often given any outstanding mines. In Rhodesia the most important are the old Tebekwe, and the celebrated Globe and Phœnix near Que Que, still exploiting after 45 years two parallel but converging veins of yellowish quartz. In the Malmani area, about Ottoshoop, reefs of quartz or brecciated dolomite trending north-north-west cut the Dolomite, some being rich at the surface.

(2) *Bedded Veins.*—For over half a century there have been worked at Pilgrims Rest in the Lydenburg district[1] gently-inclined lodes within a mountainous area 45 miles from north to south and 15 miles wide. Occurring with the Black Reef Series, Dolomite—relatively thin hereabouts—and lower part of the Pretoria Series, they conform fairly closely to the enclosing strata and dip westwards, those near the top of the Dolomite being continuous for more than a dozen miles. The ore-bodies are not continuous along any given horizon nor do bodies in the same zone lie along the same beds always. There is also a marked individuality due to the nature of the beds replaced or impregnated. Possessing a thickness ranging from a few inches to several feet, they consist of opaque white quartz with rusty cavities containing limonite from the oxidation of sulphides, mainly pyrite. The Theta and Glynn's reefs near the top of the Dolomite are well-known examples. When dolomite is the country rock, it has often been converted at the contacts through leaching into a black manganiferous earth, and is usually charged with water, which has caused difficulties in mining. Great benefit has accrued from the drainage tunnel driven beneath Glynn's from the Sabie gorge. There are in addition certain " cross reefs " called " leaders," which, while of similar composition, cut across the bedding as in ordinary fissure lodes; these are also auriferous. The veins are frequently accompanied by basic intrusive sheets, while the dolomite alongside the dioritic dykes on Vaalhoek and Graskop is mineralised, which suggests that the Bushveld Igneous Complex may have been the source of the mineralisation.

(3) *Replacements* or *Impregnations.*—These compose lenticular and often broad bodies without very definite walls, and occupy zones of shattering or shearing which traverse all types of the basement rocks, even the cherts and banded ironstones, characteristically within the

[1] A. L. Hall, *Union S.A.G.S.*, Mem. 5, 1910; W. Wybergh, Mem. 23, 1925; L. Reinecke and W. G. A. Stein, *T.G.S.S.A.*, 1930, xxxii, 73.

zone of metamorphism developed through the earlier or later phases of the " Old Granite." The potency of such shear-zones is well brought out through the 40-mile chain of mines of the Gwanda Goldbelt (*S. Rhod. G.S.*, Bull. 36, pl. vi).

The bodies may be of considerable width, though frequently their exact limits may be difficult to determine. Some of them are really " stockworks " in which the shattered rock is riddled by stringers of quartz ; in others the sheared material has been almost completely replaced by quartz or by a mixture of quartz and carbonates. The sulphide is commonly pyrite ; arsenopyrite is found at Gatooma and occasionally at Barberton, antimonite in the Murchison Range along the lengthy " Antimony line," and scheelite at the latter place and at Gatooma. Those in shattered banded ironstone are usually low-grade, with the present workings chiefly in the oxidised zone—such as to the north-west of Gwanda. In a few localities, *e.g.* some of the Sheba workings at Barberton, the deposition of the gold seems to have been influenced by zones of carbonaceous slate in the country rock.

This type of lode is well represented in each of the principal goldfields and embraces most of the larger mines, notable instances being the Planet-Slate-Arcturus group and Shamva near Salisbury, Gaika and Wanderer near Gwelo, Ayrshire near Eldorado, and Sheba, Three Sisters, and Pigg's Peak in Swaziland.

In Rhodesia [1] the Antelope, south of Bulawayo, is peculiar in having ore-bodies developed on a fault-plane in hornblende schist containing pyrite, pyrrhotite, and magnetite in a gangue of quartz, actinolite and garnet, suggestive of a high-temperature genesis. The Bushtick, that large producer south-east of Bulawayo, consists of four mineralised sections on a stretch of three miles along an east-west zone of faulting and brecciation in sheared greenstones parallel and close to the margin of the Essexvale granite. The ore-bodies are meso-thermal replacements with albite, hydrated silicates and carbonates, proved to 900 feet (Bull. 35, 119). The Cam and Motor, at Gatooma, down to over 5000 feet, and Rhodesia's deepest mine, is working, in propylitised schists and sediments, lodes made by stringers of quartz with carbonates, pyrite, stibnite, and arsenopyrite. The Eileen Alannah near Gatooma worked a big sulphide replacement in calcareous schist. In the Falcon near Umvuma the lenticular quartz lodes are heavily mineralised with iron and copper sulphides over a distance of 600 feet ; the proportion of silver recovered is nearly twice that of the gold. The Gaika at Que Que has stock-works and disseminations in magnesite rock and talc-magnesite schist carrying some arsenic, grouped along fissures. The Lonely Mine well to the north of Bulawayo—mined down to 4000 feet—is on a pitching shoot within a

[1] See *S. Rhod. G.S.*, 1934, Bull. 26, and subsequent bulletins.

narrow quartz vein 800 feet long in limburgitic greenstones considerably altered to talc-carbonate schist. Extraordinary is the fact that the lode was in spots still oxidised to below 3000 feet. A gradual drop in fineness of the gold took place with depth. The Monarch at Francistown in the Tati Territory is working lenticular quartz veins in schists near intrusive granite. The Penhalonga near Umtali runs for two and a half miles east-west in talc and chlorite schist, contains galena, and has indeed produced more silver than gold. The treacherous nature of the country rock has rendered it difficult to work. At the Rezende, Umtali's premier mine, the east-west quartzose shear-zone is hardly mineralised, is up to 100 feet wide in greenstone and carries argentiferous galena, pyrite, and a little chalcopyrite. Masses of intrusive quartz diorite and quartz porphyry are regarded as having been responsible. The Shamva, Rhodesia's largest mine, north-east of Salisbury, had an immense ore-body in fissured grits that only averaged 3 dwts., but was worked in great open stopes on the mountain side so that operating costs were low. The Sherwood Starr at Que Que is a remarkable pipe-like impregnation with some arsenopyrite in jaspilite surrounded by serpentine taking a twisting downward course, worked to 2000 feet. The Wanderer at Selukwe is a large low-grade body of quartz with pyrite between banded ironstone and conglomerate. The above are merely the larger mines.

In the Transvaal such replacement types are commonly connected with cherty "bars" as, for example, in the Sheba Group of mines, Barberton, or those of the Murchison Range—where they tend to carry antimony—but the lodes of the Consort at Noordkaap are of contact metasomatic origin and contain arsenopyrite.

B. CONGLOMERATES—(1) *The Rand Bankets.*—The immense economic importance of these conglomerates is demonstrated by the fact that the total output of gold therefrom (from 1886 to 1946) has been valued at £3,000,699,716, of which all but a fraction has come from the conglomerates of the Main Reef Series.

It was pointed out earlier (Chapter V) that the pyrite and gold are confined to the matrix of the conglomerate and, although the rock, with about 3 per cent. of pyrite, is not free-milling like the oxidised zone, the ore is by no means refractory owing to the absence of arsenical compounds. A limited amount of secondary enrichment in the upper part of the sulphide zone is suggested by the higher values obtained in the shallower levels, beneath which a decrease occurs for some distance. Despite the greater depths reached, with attendant difficulties, improved methods in mining and extraction, coupled with higher gold prices, have enabled ore with so low a content as 3 dwts. to be profitably worked in certain mines; indeed, the mean assay-value in Rand practice was 4·33 dwts. in 1938 but only 3·1 dwts. in 1947 with working costs at

about 29s. 9d. per ton. The deepest borehole (10,731 feet) is No. 2 on Buffelsdoorn 143 in the area prospected by Western Ultra-Deeps. Mining should soon be continuous from Heidelberg northwards over the entire basin of the East Rand, westwards through the Central Rand to the " Witpoortje Break " at Roodepoort, from Krugersdorp southwards through Randfontein, and after another short gap south-westwards through the West Witwatersrand Areas half-way to Frederikstad —a distance of 90 miles, with future extension at both ends, as well as down the dip to unknown depths.

The *Dominion Reefs* have been exploited from 1889 at, and are still being worked on, Rhenosterspruit west of Klerksdorp, as one or more bodies along or close to the base of cleaved sericitic quartzites resting directly on the Old Granite and dipping west at 35 degrees.

The *Government Reef Series*.—While persistent from the West Rand to Heidelberg, the Government Reef itself does not seem to be mined anywhere, nor the Promise Reefs about Roodepoort. West of Klerksdorp the Afrikander and Babrosco Mines continue working one or more discontinuous conglomerates in the upper part of the Series, while to the north-east a reef about 4 feet thick, including a conglomerate up to 2½ feet with carbon stringers in the quartzite hanging wall is mined at the Buffelsdoorn. Downfaulted on the south-east, much boring has been done to prove its possible extension in that direction.

The *Jeppestown Series* contains hardly any auriferous bodies, an exception being the Veldschoen Reef, worked for a time on the Vaal River near Vredefort.

The MAIN REEF ZONE.—As pointed out on p. 82 the several component reefs, included within from 20 to 150 feet of strata, are remarkably persistent, though at Randfontein a greater number appear.

The thin though valuable *Carbon Leader* is present only on the Far West Rand, making its entry at the southern end of Libanon and extending westwards through West Driefontein and Blyvooruitzicht—where it is being mined—over parts of Varkenslaagte and onwards to Gerhardminnebron at least. It dips regularly southwards at about 30 degrees and has been proved in Western Ultra Deeps at over 7000 feet, and elsewhere down to 10,000 feet.

The *North Reef* is thin and poorly mineralised and nowhere worked.

The *Main Reef* is present over the Far West as well as the West Rand, swelling out to 20 feet or more in places at Venterspost and Randfontein Estates (" West Reef "). It is strong and from 4-5 feet generally, though up to 10 or 12 feet in the Central Rand, and is mined on a large scale from Witpoortje to Simmer and Jack, though only slightly between the Consolidated Main Reef and Crown Mines.

The variable *Bastard Reef* is often mineable, especially where it thickens, as at the Rose Deep and Witwatersrand.

The *Main Reef Leader*, several feet higher up, with larger pebbles, continues to be the chief producer in the Central Rand, particularly in the Langlaagte Estate, City Deep, Crown, Robinson Deep, Nourse, and Simmer and Jack, right down to the deepest levels, and in the East Rand, where it is the dominant reef, but peters out westwards in the Durban Roodepoort. Conspicuous over the East and Far East Rand is the shoot-like distribution of pebbles and gold values (p. 107). The so-called " Boksburg Gap " is due merely to poorer development and mineralisation within the outcrop section around the sharp bend made by the reef-zone through the northern part of the Van Dyk.

The *Banded Pyritic Quartzites*, more particularly those in the footwall of the Main Reef and Main Reef Leader, are extracted at a profit on various properties, for example the Meyer and Charlton, and Simmer and Jack.

The *South Reef*, from 2-5 feet thick, comes second as a producer on the Central Rand and is a good contributor at the Langlaagte Estates, at Randfontein—as the so-called " Leader "—and Crown, and the most important reef at the Nourse Mine. Parted from the M.R. Leader by from 70 to 110 feet so far as Simmer and Jack, it merges with the former in the E.R.P.M.

The *Upper Leaders*, though irregularly developed, are being extensively mined, and, in the case of the Van Rhyn Estates, Van Rhyn Deep and New Modder, furnish the major part of the tonnage milled, becoming less important towards the east.

The *Livingstone Reefs* are payable in one portion or another of this reef-zone, over a width of up to a few feet (with small pebbles) in the west at Randfontein Estates and then, after a long gap, between Van Rhyn Estates and Modder Deep.

The bands composing the *Bird Reefs* occupy a width of 150-300 feet within the quartzites. They are worked at West Rand Consolidated—as the Monarch and White Reef—and far to the east again at Rand Leases and Consolidated Main Reef.

The *Kimberley Reefs*, six or more, including some thick bodies, are spaced within 400-600 feet of quartzites and carry largish pebbles, and occasionally carbon and buckshot pyrite. On the West Rand they are producing a large tonnage as the Lindum and Horsham Reefs of Randfontein Estates and West Rand Consolidated, and eastwards at Consolidated Main Reef. Although traceable through the Central Rand, they are only workable again beyond Benoni at Southern Van Ryn, Modder Deep, Daggafontein, and Vogelstruisbult near Nigel. Thereafter the pebble-beds dwindle, but have been worked in a few small mines south of Greylingstad, notably at the old Heidelberg-Roodepoort.

The coarse variable pebble-beds of the *Elsburg Series* have been mined at only a few spots. The " Ventersdorp Contact Reef " is referred to elsewhere (p. 120).

In *Klerksdorp* the presumably " Main-Bird " *Commonage Reef* is exploited on the Town Lands, dipping eastwards in repeatedly faulted ground, with the higher *Vaal Reefs* that have recently been proved beneath the Dolomite to the east. The " Kimberley-Elsburg " *Gold Estates Reef* has been mined on the Town Lands as well, while other conglomerates are being worked at Western Reefs.

In the *Odendaalsrus area* only through actual development from the shafts now being sunk can the peculiarities of the important conglomerates be established. For the present the slightly thinner *Basal Reef* will constitute the dominant one, with higher values in the south-east. The *Leader* is nevertheless rich in some spots, particularly in the south-west, which suggests that the area south of the Zand River may become of importance. Promising also are certain lower as well as higher pebble-beds.

In Zululand the " banket reefs " at the Denny Dalton Mine on the White Umfolosi, in the Insuzi and Umhlatuzi Valleys, at Nondweni and on Rondspring in the Pivaan Valley, Vryheid, in the Pongola System, have been worked spasmodically, but are thin and distinctly low-grade.

(2) *The Black Reef Conglomerates.*—In the past much work was done on these reefs, not only in the Transvaal but in Bechuanaland, and indeed the possibilities of this formation have not been exhausted. They were formerly mined at a number of places near the Rand, *e.g.* Natal Spruit south of Germiston, in the Klip River Valley, extensively on Nooitgedacht and Eleazar between Klerksdorp and Potchefstroom, also far to the east in the Haenertsberg overlooking the Letaba Valley, as well as at several points along the Great Escarpment. While the " banket " was very rich in places, the reef was often patchy and not uncommonly of a refractory nature, added to which were troubles due to the influx of water from the overlying Dolomite. Mining is proceeding at Krugersdorp, in Klerksdorp and other places, the chief producer being the New Machavie Mine on Eleazar. Values are being found in associated pyritic quartzites as well as in the conglomerates. Promising results are being obtained on the East Rand also, *e.g.* Government Areas, where a large lense occurs. In several cases the gold must largely have been derived from the erosion of Witwatersrand bankets beneath, or nearby.

(3) *The Eldorado Banket.*[1]—There has been some discussion about this occurrence in Rhodesia, which had the form of a narrow shoot in the thick basal conglomerate of the Eldorado Series that rests unconformably on sericite schist with a poorer parallel reef in the hanging wall. To-day it is only being worked near the surface. The gold is

[1] J. W. Gregory, *Trans. Inst. Min. Metal*, 1906, xv, 563 ; H. B. Maufe, etc., *S. Rhod. G.S.*, 1923, Bull. 9 ; A. M. Macgregor, *ibid.*, 1947, Bull. 38, 15.

present as films (" paint gold ") along planes in the schistose matrix or in cracks in the pebbles. The boundaries of the body, though not obvious, are reported to be sharp only along the footwall and the conglomerates elsewhere to be barren. While subsequently regarded as an impregnation, there would appear to be much to be said for Gregory's original view of alluvial patches or shoots within a conglomerate body in which the gold had become rearranged by subsequent recrystallisation, as in the Rand Banket.

C. ALLUVIALS.—Rarely have conditions been such as to favour the accumulation of auriferous deposits of this kind, though some, in part eluvial, are worked in the Pilgrims Rest area. The Revue Dredging Co. is, however, most successfully dredging the lower Revue and Chua Rivers in Portuguese East Africa.

Iron.—South Africa is wonderfully well supplied with iron ores, though geographical and other considerations have long delayed their exploitation.[1]

(*a*) In the Bushveld region, Murchison Range, and lower Tugela Valley there are considerable bodies of magnetite which could readily be mined, but unfortunately they all carry high percentages of titanic acid (from 14 to 20), which militate against their exploitation in view of the larger deposits of hæmatite available.

(*b*) The bulk of the other ores are beds of sedimentary origin or represent secondary enrichments of such stratified ferruginous layers. Outstanding are the Banded Ironstones or " itabirites " of wide distribution in Southern Rhodesia (Salisbury, Bulawayo, Selukwe, Gatooma, etc.), the eastern Transvaal (Haenertsberg, Barberton, Pongola), Zululand, and less abundantly in South-West Africa (Walvis), running in belts and generally making massive outcrops in the schist formations ; they are also present in the Witwatersrand System.

Consisting of alternating laminæ of magnetite, hæmatite, and chert, frequently contorted, they possess a metallic content of from 15 to 40 per cent. and are therefore comparatively low-grade, while the occasional presence of apatite in needles suggests a phosphoric character. In places where they are traversed by lines of shear there may be a considerable rise in the iron-content owing to replacement of the siliceous matrix by hæmatite, while the magnetite has simultaneously been converted into the sesquioxide. A large deposit occurs at the Lime Works, Que Que ; there is another one near Ottosdal, Transvaal ; a third is " Iron Hill " in north-west Swaziland near the Havelock Mine, situated on an anticline in the Fig Tree Series (Mehliss).

[1] P. A. Wagner, *Union S.A.G.S.*, 1921, Mem. 17 ; 1928, Mem. 26 ; *Min. Res. Un. S.A.*, 1940, 236-50.

(*c*) The Pretoria-Griquatown Beds form the iron-bearer *par excellence*, particularly the Banded Ironstone group overlying the Dolomite, which, while normally carrying from 10 to 40 per cent. of iron, has been enriched within zones of fracturing.

(1) *Postmasburg area.*—Dotted over some 40 miles of country north from Postmasburg and often close to the railway, lie numerous masses —capping hills—some of great size, including many of high-grade hæmatite ores. These are of two classes:[1]

(i) The *Blinkklip Type* (p. 159) making flat-lying cappings of black or blue-black colour, breaking into roughly rectangular blocks of all sizes with fine banding showing up on weathered surfaces and with the spaces in between them cemented by hæmatite. There are also extensive associated scree-deposits easy to work. Examples are the Klipfontein Hills, Blinkklip, Gamagara, and Bruce.

(ii) The *Conglomerate Type* (p. 206) has been produced where the Gamagara basal conglomerate—carrying hæmatite pebbles—has had its matrix replaced by ore; locally it is manganiferous. It weathers into large spheroidal masses. Examples are Bruce, Mokanning, and Gamagara.

(2) *Thabazimbi.*—From this huge deposit in the Rustenburg district the South African Iron and Steel Industrial Corporation (Iscor) has since 1931 been meeting its ever-increasing demands.

Near Vliege Poort on the Crocodile River the Banded Ironstones overlying the Dolomite dip south at angles of from 40° to 50°, are repeated by thrust-faulting (Fig. 23, 3c) and build two east-west ranges (p. 133), the more important northern one rising to 2000 feet above the valley and being known as Thabazimbi—the "Mountain of Iron." Along a strike of over two miles and to unknown depths there have been extensive enrichments within the lower part of the group, giving a connected series of tabular bodies and lenses of varying though considerable width that furnish an ore of exceptional quality—from 60 to 69 per cent. of iron, with 0·006 to 0·05 per cent. of phosphoric oxide and 0·0 to 0·03 per cent. of sulphur. It ranges from solid striped hæmatite to brecciated varieties, highly jointed in parts. Outcrops on the hillsides well display transitions, gradual or sharp, from lean ironstone to rich ore. The hæmatitisation has in part been later than the fracturing (de Villiers).

The deposit is worked from a series of levels 350 feet apart vertically, driven within the top of the Dolomite with cross-cuts to the overlying, steeply-dipping ore-body. The ore is railed 155 miles for smelting by Iscor at Pretoria, the ore railed to Pretoria at present

[1] *Union S.A.G.S.*, 1938, Expln. Sheet 173; J. E. de Villiers, *T.G.S.S.A.*, 1945, xlvii, 123; D. J L. Visser, *ibid.*, 197.

amounting to about 90,000 short tons per month. Lesser deposits occur along this, as well as the southern range.

The enrichment of the Ironstones was clearly connected with the post-Waterberg faulting and thrusting, in presumably relatively shallow-seated zones, but there are differing opinions regarding the precise mode and stages of such replacement.[1]

(*d*) The other bands in the Pretoria Series are much thinner and are rather like the minette ores of Alsace-Lorraine. The lower one in the Timeball Hill group is a wonderfully persistent siliceous oölitic ironstone from 7 to 20 feet thick containing 44 to 53 per cent. of iron, 0·14 to 0·24 per cent. of phosphoric acid, and 0·014 to 0·03 per cent. of sulphur; the upper is a clayband ironstone, with oölites of chamosite and magnetite in a matrix of siderite and chamosite, about 2 feet thick with 51, 0·05, and 0·02 per cent. respectively. These two beds have been mined and smelted with success at Pretoria.

Beneath the Daspoort Quartzite is an oölitic ironstone from 3 to 5 feet thick, running through Pretoria and traceable for a distance of almost 200 miles; though usually low-grade it has several stretches wherein a metallic content of 50 per cent. is attained, *e.g.* near Potchefstroom. Where affected by thermal metamorphism it consists of specularite, magnetite, quartz, muscovite, and a vanadium-bearing mica; indeed, it is remarkable to observe that this rare element (vanadium) has also been detected in the Timeball Hill clayband.

(*e*) An extensive, but low-grade, deposit is that on Kromdraai, south-east of Pienaars River Station, where, on hills dotted with ancient workings, stratified agglomerate and tuffs, regarded by Wagner[2] as belonging to the Rooiberg Group, but possibly merely Basal Waterberg, have been intensely though variably hæmatitised.

(*f*) In the Coal Measures of Natal bedded ores of variable composition are known, *e.g.* at Prestwick near Dundee, their thickness ranging from 2 to 6 feet; magnetite may be present as well as hæmatite.

Lead and Zinc.—In comparison with the enormous deposits of these ores at Broken Hill in Northern Rhodesia, the occurrences south of the Zambezi pale into insignificance. Galena and to a lesser extent zincblende are present in many of the auriferous veins, particularly those of Rhodesia, while the silver content has generally been the inducement towards the recovery of the lead, *e.g.* at Penhalonga near Umtali, which is the largest producer, Tsumeb in South-West Africa, and Argent on the Springs-Witbank railway.

The important deposits of Tsumeb have been mentioned under

[1] J. W. du Preez, *Ann. Univ. Stellenbosch*, 1944, xxii, Sect. A, 263; J. E. de Villiers, *T.G.S.S.A.*, 1945, xlvii, 123.

[2] P. A. Wagner, *loc. cit.*, chap. iv.

"Copper," with which the Lead and Zinc ores are associated. The lead reserves are estimated at over 200,000 tons. In the Abenab West Mine, to the east, the vanadium body carries about 18 per cent. of cerussite. Two apparently large lead deposits are that at Hohewarte south-east of Windhoek along with copper and silver, and that at the Namib Prospect, Swakopmund district, along with zinc and silver, both in crystalline limestones. The curious silver-lead ores at Aiais, Warmbad district, are associated with igneous plugs, dykes, and breccias.

The dolomite of the Transvaal and Griqualand West is dotted with small deposits, many of which have been worked, though few would seem worthy of attention under present conditions.[1] Those in the Marico district [2] are generally at the top of the Dolomite, occurring either as disseminations in the latter following the bedding (Doornhoek) or as curious localised areas less than 100 yards across that are set vertically and have a pipe-like form (Witkop). They all contain galena, zincblende, manganese ores, sometimes barite and fluorite, together with secondarily derived minerals at the outcrop. Galena predominates at Doornhoek; zincblende at Witkop and Buffelshoek. The dolomite which has been replaced by the sulphides is often full of tremolite and sometimes talc, pointing to the Bushveld Complex as the source of the mineralisation, while a similar genesis can be ascribed to the galena lodes worked near Argent Station and Edendale north-east of Pretoria.

Limestones.—The bulk of this material when quarried is used in the manufacture of lime and cement or for agricultural or chemical purposes and only a small proportion is used as a building stone (*q.v.*).

The sources consist of (*a*) *Primary limestones*, the compact or crystalline limestones and dolomites of the pre-Cape formations, and (*b*) *Secondary limestones* of Tertiary or Recent age,[3] though such are not often well situated.

(*a*) In the former category come the numerous belts of "marble" in the granite and gneiss-country of the northern half of South-West Africa, Southern Rhodesia, Portuguese East Africa, the Limpopo Valley, Leydsdorp, the Tugela Valley, and the "Marble Delta" in Natal, the material being commonly pale in colour, medium to coarse in grain, almost invariably *dolomitic* in composition and in places full of impurities in the shape of layers rich in contact-silicates. Next come the still larger and more extensive deposits of the Transvaal and

[1] *Union S.A.G.S.*, 1944, Mem. 39.

[2] W. Kupferburger, *T.G.S.S.A.*, 1927, xxix, 5.

[3] A great deal of valuable information on this subject will be found in W. Wybergh's two volumes, *The Limestone Resources of the Union*, *Union S.A. G.S. Mem.* 11, 1918 and 1920.

Nama systems—the grey and brown-weathering dolomites and limestones of Griqualand West, Otavi region, Namaland, Namaqualand, Van Rhynsdorp, Cango area, Gamtoos Valley, Transvaal, and Lomagundi district.

Among the primary limestones there is generally no difficulty in obtaining a rock low in silica, iron, and alumina (together under 5 per cent.) and high in carbonates, though it is not always possible to find one low in magnesia (under 5 per cent.) as well. At Claremont near Bulawayo and again close to Salisbury crystalline limestones are being worked that are very low in magnesia, while many of the Nama limestones and certain of those of the Campbell Rand and Cango are also low in that base and are quarried for cement-making near Piquetberg in the Cape and Loerie (Gamtoos), or for lime as at Norree near Robertson or Marble Hall. On the other hand, some of the rocks are almost chemically pure dolomite, for example that at the Sinoia Caves, Lomagundi.

Commercially, a high magnesia-content (15-20 per cent.) is usually a disadvantage; the dolomitic limes are slower in hardening than the calcic ones, though in time the mortars formed from them are quite as strong as those obtained from the latter. The product from the Transvaal Dolomite is indeed extensively marketed under the name of " Blue Lime."

(*b*) The secondary limestones have largely been derived from pre-existing limestones or from the decomposition of lime-bearing basic igneous rocks in their neighbourhood, the peculiarity being that they are much lower in magnesia than the parent formations, but higher in silica, iron, and alumina (together from 8-15 per cent.). Such *surface limestones* have a huge distribution in South Africa, both along parts of the coast and in the interior, as described in Chapter XVII. Owing, however, to their mode of origin, such " sheet limestone " may contain a good deal of foreign matter, chiefly sand or small pebbles; and this is particularly true of the western Transvaal, Griqualand West, and much of the Kalahari region, though it is possible to find commercial deposits of sufficiently pure material.

The solid or partly crystallised shelly limestones of the Tertiary Alexandria and Bredasdorp formations in the south of the Cape, and also the tufa encrusting them, are rather pure and furthermore low in magnesia, the same applying to many of the deposits in the coastal belt, although when close to the shore an admixture of wind-borne sand is not unusual, *e.g.* Saldanha Bay, Port Elizabeth, and Portuguese Territory.

The secondary limestones in addition to their lower magnesia content are, because of their more porous nature, more readily calcined than the primary ones, while, when merely finely ground up, they furnish an " agricultural lime," as that railed from Halesowen Station

near Cradock. On Weltevreden near Zeerust an exceptionally pure " vlei limestone " is so powdery that it is worked for such a purpose without grinding. For certain industrial purposes over 2 per cent. of magnesia is not permissible, for example in the manufacture of cement or carbide, or in sugar refining. Associated, however, with the Dolomite, either in caves—as at Krugersdorp or Makapansgat, near Potgietersrust—or from springs—particularly along the edge of the Kaap Plateau—are accumulations of high-grade travertine, cliff-limestone, or " drip-stone " suitable for such purposes. An extensive body is being quarried at Buxton opposite Taungs, while a second is being developed at Thoming nearby, with a third working at Ulco to the south-west along the Postmasburg railway. Another mass of such travertine exists on California near Ohrigstad, Transvaal.

Magnesite.—Amorphous magnesite low in iron, lime, and silica occurs as veins and irregular bodies in the zone of weathering in ultrabasic rocks in the Union at (1) Burghersfort, Lydenburg, in Bushveld pyroxenite, (2) the Sutherland Range near the Klein Letaba, and (3) the Kaapmuiden area, where the reserves are to-day limited.[1]

Large deposits are being mined in Rhodesia 8 miles east of Gatooma from a body over a mile long and 100-150 feet wide dipping steeply, that has resulted apparently from the decalcification of a dolomite of the Shamvaian System, and shows a brecciated structure.

Manganese.—The immense ore-zones in the Postmasburg area [2] occupy two belts trending north-south, united at their ends, the western one straight and continuous for 38 miles, the eastern one curved and eroded into a chain of outliers, with additional bodies farther to the west and north. They have originated on or near the junction of the Dolomite and its covering of Griquatown or Gamagara (Matsap) beds, and are seemingly hypogene replacements of chert, breccia, conglomerate or shale by waters bringing up manganese and iron through solution of the supporting Dolomite, as the result apparently of post-Matsap compression and overthrusting from the west. Almost everywhere the mineralised zone has dolomite as the footwall with a highly irregular junction, due to solution of the latter, tongues of ore descending into it in many places. Over much of the region the manganised zone passes upwards with greater or less definition into a ferruginised portion.

In the *Eastern Belt*—Beeshoek, Klipfontein, Kapstewel, Maremane,

[1] *Union S.A.G.S.*, 1942, Mem. 38.

[2] A. L. Hall, *T.G.S.S.A.* 1926, xxix, 17; L. T. Nel, *Union S.A.G.S.*, 1929, " The Geology of the Postmasburg Manganese Deposits "; A. L. du Toit, *Econ. Geol.*, 1933, xxviii, 95; F. C. Truter, *et al.*, *Union S.A.G.S.*, 1938, Expln. Sheet 173; *Min. Res. U.S. Africa*, 1940, 262; D. J. L. Visser, *T.G.S.S.A.*, 1945, xlvii, 197; J. E. de Villiers, *ibid.*, 123.

Dimaneng—the ore-bodies are detached highly irregular and in places diffuse replacements of chert, chert breccia or Blinkklip breccia, and include some high-grade material, with a lot of detrital ore on the slopes, part of which is recoverable.

In the *Western Belt*—Beeshoek, Gloucester, Lohatla, Bruce—the ore-body is less discontinuous and is sheet-like, although cutting gradually across the stratification of the enclosing strata, the bulk being a replacement of conglomerates, grits, and aluminous shales. It includes much poorly manganised, ferruginous, or barren-rock, the upper levels being usually high in iron, and passes beneath Gamagara quartzites or overthrust Griquatown Beds. The mineable portion ranges from a few to many feet in thickness and has in spots been proved to continue to depths of 120 feet at least.

To the *West* on Aucampsrust and Kameelhoek the ore-zone is brought up in an anticline within a tectonic "window."[1] About 100 miles to the *North* there projects through the sand the "Black Rock," where ore-bodies 15-25 feet thick dipping westwards have been formed within the Griquatown jaspers.[2]

The Postmasburg ores are massive, hard, and of excellent quality, composed essentially of pyrolusite, manganite, and sitaparite (bixbyite) accompanied by wad, rhodonite, barite, diaspore, lithiophorite, ephesite (soda-margarite) and opaline silica, especially in druses. As mined, they contain from 42-54 per cent. of metallic manganese, 7-15 per cent. of iron, and 6 per cent. of silica, with exceptionally low sulphur and phosphorus. Lately there has been demand for lower-grade though more ferruginous kinds. Although the workings are mostly on slopes, the question of overburden is a vital factor. Mining has principally been from the more accessible southern half of the fields, the ore being railed about 750 miles to Durban for export.

The total output of ore for 1951 was 836,515 tons valued at £3,982,000. The reserves are confidently believed to be enormous.

The small bodies of pyrolusite in the Table Mountain Sandstone, as at Constantia Nek and Hout Bay near Cape Town, Du Toits Kloof near Paarl, and that deposited by the hot springs at Caledon, have originated along lines of fracture by leaching from the sandstones, and are in places phosphoric.

The Dolomite of the Transvaal commonly carries small proportions of manganous carbonate, and weathering of the rock has often led to the formation of manganiferous earth, as along certain horizons in Zeerust, Pilgrims Rest, and Carolina, or to the production of lateritic manganese ores, as at Elandsvlei west of Krugersdorp. While the percentage of manganese dioxide may exceed 60, a very small amount of lead from the traces of galena in the parent rock prevents it from

[1] L. G. Boardman, *T.G.S.S.A.*, 1941, xliii, 27.
[2] L. G. Boardman, *ibid.*, 1942, xliv, 51.

being exported for steel making, though for other purposes it is satisfactory. Lateritic ores are also found near Somabula in the Gwelo district, though they are of low grade.

Mica.—Although a conspicuous constituent of the coarse feldspar-pegmatites so common in the Basement Complex, muscovite-mica is rather seldom found in large sheets that are devoid of flaws and wrinkles. Furthermore, the generally irregular behaviour of these veins leads to much waste in mining, and these facts have greatly restricted the exploitation of such bodies, though " waste-mica " has become a profitable business.

The workable deposits are practically confined to the region about Miami in the Angwa valley, Lomagundi district,[1] enclosed in mica schist and quartz schists, to the belt several miles wide along the southern margin of the Palabora Granite near Leydsdorp,[2] in veins traversing gneiss, and to the Letaba area. The " books " of mica are usually very irregularly distributed within the pegmatites, but in the first area they tend to be collected along the walls of the veins, being associated with occasional tourmaline and beryl. The allied and extremely useful industrial mineral *Vermiculite* is being extracted on a great scale from pyroxenite at Palabora (p. 63).

Nickel.—The deposits on the farm Vlakfontein, No. 902, to the south-west of the Pilansberg in the Rustenburg district have been well described by Wagner, with additions by Hoffmann, Schoch, and Schwellnus.[3] Greatly extended work has shown that such mineralisation is not confined to Vlakfontein but has affected a wide zone trending northwards for 20 miles, disclosed by a multitude of gossan-cappings of red ferruginous highly opaline material arranged in clusters. Each gossan passes in depth into a sulphide body, pipe-like, roughly vertical, that cuts across the pseudo-stratification of the bronzitite and related rocks of the Bushveld Norite, the ore tending to be disseminated along the margin and massive towards the centre ; associated are sulphide-bearing basic pegmatites. These deposits, which strongly recall the platiniferous " pipes," are regarded as essentially of magmatic origin. The principal minerals are pyrrhotite, pentlandite, and chalcopyrite, with marcasite in the upper levels. The ore so far proved carries about 3 per cent. of nickel and 1 per cent. of copper, with a small and variable proportion of precious metals.

The great sill of gabbro-norite at Insizwa, Mount Ayliff (p. 365), carries sulphides in its basal olivine-rich phase, the ore being seemingly

[1] H. B. Maufe, *S. Rhod. G.S. Short Rep.*, No. 10, 1920.

[2] A. L. Hall, *Union S.A.G.S.*, Mem. 13, 1920 ; *S.A.J.I.*, 1924, vii, 798.

[3] P. A. Wagner, *Union S.A.G.S.*, Mem. 21, 1924, where previous literature is mentioned ; C. M. Schwellnus, *Union S.A.G.S.*, 1935, Bull. 5 ; P. L. de Bruyn, *Ann. Univ. Stellenbosch*, 1944, xxii, Sect. A, 63.

restricted to hollows of the floor, which consists of hornfelsed sediments. Chief among the many minerals present are pyrrhotite, pentlandite, chalcopyrite, and cubanite. The ores occur as disseminations through the olivine-norite and picrite—the average content being from 7 to 8 per cent.—or as veins and sheets of massive sulphides, which are either rich in or free from pyrrhotite. The former contain from 0·3 to 2 per cent. of both nickel and copper; the latter from 3 to 5 per cent. nickel and 3 to 20 per cent. copper. Gold, silver, and platinoids are present in appreciable amounts. From the increase in the mineralisation with depth, it is believed that workable deposits may underlie the deeper parts of the range,[1] though recent work has failed to disclose any large bodies.

Near the Scotia Talc Mine, Barberton, a sedimentary bed up to 2 feet thick has been discovered containing the mineral trevorite, a magnetic nickel oxide, sulphur being absent. At the Noel Mine, Lower Gwanda, veins in serpentine carrying nickel arsenide are being worked. The pyrrhotite associated with chalcopyrite at the Umtali Copper Mine, Rhodesia, is said to assay up to 4 per cent. of nickel. Garnierite occurs sparingly in the serpentine of the Great Dyke.

" Oil-shale."—The search for oil-yielding rocks has revealed seams of so-called " oil-shale " in the Union, although this term is an inexact one, since the material is in general not shaly and only furnishes oil upon destructive distillation. The " oil-shale " of the Impendhle district, Natal, is actually a bright coaly substance interlaminated with black shale, not very far removed from a cannel coal; indeed, certain bituminous coals are known to furnish from 10 to 25 gallons of oil per ton on test, particularly those associated with the stuff under consideration.

The typical South African "*Torbanite*" is very like Scottish *Boghead*, being tough with a blackish lustre, brown streak, and conchoidal fracture and giving a dull wooden sound when struck by a hammer. With a few exceptions the occurrences belong to the Ecca Coal Measures, coals being usually present on higher or lower horizons. Frequently indeed the torbanite forms part of a coal bed, from which it may be sharply defined; on the other hand, it may pass through carbonaceous rock into barren shale. The higher-grade material occurs in bands from a few inches up to a foot in thickness, but is occasionally more, while the bodies of low-grade " shale " may reach 6 or 8 feet in thickness.

The occurrences are sparsely dotted over the region between Breyton, Ermelo, Wakkerstroom, and Utrecht,[2] but future investigation is sure to prove their greater extension. As a typical section, that

[1] See D. L. Scholtz, *T.G.S.S.A.*, 1937, 81.

[2] *Min. Res. Union S.A.*, 1940, 402; R. Stelling, *Jnl. Chem. Met. Min. Soc. S.A.*, 1942, xliii, 34.

on the farms Kromhoek and Virginia east of Wakkerstroom may be quoted :—Sandstone (roof), " oil-shale " 24 to 33 inches, shale 24 inches, " oil-shale " 0 to 20 inches, coal 2 to 4 inches, sandstone (floor), the mineable width being about 30 inches. Along the extension of this horizon into Winterplaats and Spruitfontein about 3 feet might be workable out of 7. An exceptional assay of 98 gallons of oil per ton has been obtained, but 30 to 40 gallons per ton may be taken as probably representative, while the low-grade qualities should furnish from 20 gallons downwards; the yield of ammonium sulphate is generally from 10 to 15 lb. per ton.

On Mooifontein, Ermelo, a persistent seam 13 to 27 inches thick, beneath a 30-inch bed of coal, is worked from a depth of 100-200 feet by the S.A. Torbanite Mining Co., the yield continuing to be just over 45 gallons per ton.

In thin section under the microscope the torbanite shows characteristically in its opaque groundmass abundant transparent yellow oval or flattened sacs of the oil-alga *Botryococcus*, along with plant spores and colloidal organic matter.

Torbanites the world over are known to be much less persistent than coal seams, which explains why the prospecting in the Union has proved their lateral passage into barren shale within comparatively short distances. Much exploratory work must therefore be done before the average thickness and value of a seam can be established, even over a very limited area.

Petroleum.—The lithological characters of even the more likely formations in South Africa, their general continental origin and the absence of suitable structures are distinctly adverse to the finding of petroleum in commercial quantities.[1]

(*a*) Polymerised hydrocarbons occur in veins in the Fish River beds to the north-west of Keetmanshoop, but a boring 3275 feet deep through the slightly bituminous Schwarzkalk on a structural dome near Bethanie proved a failure.

(*b*) Although the Folded Belt along the south of the Karroo has given encouragement through its various pitching anticlinal structures and the presence over wide areas of veins of pseudo-coals cutting the Beaufort beds, the borings so far made, including one of 9000 feet north of Fraserburg Road, have not proved encouraging.

(*c*) Within the Karroo System small quantities of an oily or tarry material have been found in many spots in the northern half of the Karroo and Free State, usually in cavities or joints in intrusive dolerite or strata adjoining. Their precise nature not having been appreciated, they have led to much fruitless prospecting, as for instance in the

[1] A. W. Rogers, *Union S.A.G.S.*, 1917, Mem. 8.

5000-foot boring at Dubbledevlei north of Carnarvon (down through Karroo beds far into the basement granite), and also that at Elandsdraai, Orange River Station, both of which pierce the carbonaceous " White Band."

In the Coal Measures a few spots are known, such as near Dannhauser in Natal, where the sandstones are locally impregnated with mineral oil. In the Barkly East district pitch has been found in crevices in the agglomerate filling a large volcanic neck piercing the Stormberg beds and also in joints in basalt. At Madrid near Bethlehem the basal sheet of lava resting on the Cave Sandstone contains for quite a distance amygdales filled with calcite and a black glossy hydrocarbon, apparently a much altered (polymerised) pitch, while elsewhere in the district such lavas carry some oil.[1] One cannot doubt that these " pyrobitumens " have been due essentially to the distillation in depth of carbonaceous shales or coals belonging to various horizons by the dolerite magma, to their upward transfer and condensation within joints and vesicles, though a purely chemical source is not in certain cases excluded. A similar origin can be ascribed to the natural gas struck in the Coal Measures near Devon in the Heidelberg district and elsewhere. Identical " indications " are widespread within the Paraná Basin of Brazil with its similar sediments and dolerites, wherein extensive deep drilling has so far been unsuccessful.

(*d*) More promising is the marine Cretaceo-Tertiary, particularly in the less explored territories of Moçambique, where anticlines favouring the trapping of oil are either known or can be expected. On such a closed structure at Inyaminga north of Beira five boreholes, the deepest of 8083 feet, were drilled (p. 407), though without result, the material pierced in depth being sandy to gritty and apparently unsuited for the generation of petroleum.

The 872-foot boring in fossiliferous Cretaceous in 1907-8 at Lake Nhangela, near Inhambane, is, however, alleged to have yielded some oil and bitumen. The Cretaceous is reported to build two gentle anticlines between Inhambane and Jinabai. The shallow boreholes sunk in this Series in the area between Lourenço Marques and Zululand have so far been unsuccessful.

Phosphate Rock.—South Africa is notoriously deficient in rock-phosphates readily available as fertiliser. The significant occurrences are of both igneous and sedimentary origin.

(*a*) *Apatite*—essentially fluorapatite—with 35-40 per cent. of P_2O_5, occurs in great amount at Palabora 25 miles east of Mica Siding in the eastern Transvaal as lenses, patches, and disseminations in pyroxene-

[1] A. L. Hall, *T.G.S.S.A.*, 1921, xxiv, 98 ; O. R. van Eeden, *Union S.A.G.S.*, 1937, Mem. 33.

rock associated with calcite, mica, and vermiculite.[1] At one time the mineral was separated and very finely ground, but it is learned that a new process has recently been devised for rendering the phosphoric content more assimilable. Apatite is also present in some quantity in pegmatites near Bandolierkop Station.

A comparable occurrence is being developed at Dorowa in the Upper Sabi Valley near the 19th parallel in Rhodesia, where rocks containing magnetite or vermiculite are associated with limestone and intrusive syenite.[2]

(*b*) At Saldanha Bay and at Langebaan in the Cape hard brownish crusts in considerable amount, produced by the phosphatisation of granite or quartz porphyry, carry from 15-28 per cent. of P_2O_5, though mainly in combination with iron and alumina and thus not easily assimilated by plants.[3] At Langebaan Road (Langebaanweg) Station a variable layer, including nodules of phosphate of lime and phosphatised clay resting on sand, is being successfully worked up into a fertiliser having from 17-19 per cent. phosphoric acid.[4]

Concretionary nodules and lenses containing phosphate of lime are scattered along the outcrops of the Upper Dwyka Shales of the southern Karroo (p. 278) and the Upper Ecca Shales of northern Natal (p. 289), but their exploitation is not economic.

Platinum Metals.—Outstanding have been the discoveries of the enormously widespread distribution of these precious metals, principally in the Bushveld Region, but in Southern Rhodesia as well, as the result of which an industry has been built up in the central Transvaal.[5]

The principal types represented are :—(1) *Direct segregations* within the parent basic or ultrabasic rock ; (2) *Contact metasomatic deposits* associated with (1) ; (3) *Quartzose veins* ; (4) *Witwatersrand conglomerates* ; and (5) *Alluvial deposits*. The platinum is often alloyed with palladium and other metals of the platinum group, wherefore the term " platinoids " is sometimes used.

(1) *In Norite and Dunite.*—The bulk of the finds belong to this class and occur within the sheet-like norite body of the Bushveld " Lopolith " (p. 184, Figs. 22 and 28), or in the related " Great Dyke " of Rhodesia (p. 196), embracing so far as can yet be judged all those of economic importance. The majority are furthermore confined to a

[1] C. M. Schwellnus, *Union S.A.G.S.*, 1938, Bull. 11.

[2] F. P. Mennell, *Geol. Mag.*, 1946, lxxxiii, 137.

[3] A. L. du Toit, *Union S.A.G.S.*, 1917, Mem. 10.

[4] S. H. Haughton, *T.G.S.S.A.*, 1933, xxxv, 119 ; J. J. Frankel, *S.A.J.S.*, 1943, xxxix, 102.

[5] P. A. Wagner, *The Platinum Deposits and Mines of South Africa*, 1929, with reference to earlier literature, the mineragraphy of the ores being dealt with by H. Schneiderhöhn ; *Min. Res. Union S.A.*, 1940, 186.

strip of country a few miles wide in the Potgietersrust, Lydenburg, and Rustenburg districts, the chief habits of which have been classified by Wagner as follows :—

(a) *In Hortonolite dunite*, an extraordinarily heavy black rock (sp. gr. 3·7) composed of an iron-rich olivine (hortonolite) occurring in pipe-, carrot-like or irregular bodies in olivine (magnesia-rich) dunite, bronzitite or serpentine cutting the basal part of the norite. Sulphides are absent, though significantly a fluorine-bearing mica is present, and the platinum occurs in the metallic state as tiny cubes or irregular grains.

Of the many cases known the most important are those on Onverwacht, Mooihoek, and Driekop in Lydenburg, the body in the first-named being pipe-like, some 60 feet in diameter and worked to a depth of nearly 800 feet, that on Mooihoek being 45 feet across and proved to 400 feet. While the platinum content is variable, values up to several ounces to the ton were obtained.

(b) *In Chromitite*, in stratified bands up to a few feet thick, which assay from 2 up to 12 dwts. per ton on Zeekoegat, Forest Hill, Mooihoek, etc., in Lydenburg, and Kroonendal (Kroondal), in Rustenburg, the platinum being contained in the silicates in a minute state of division.

(c) *In Norite*, forming well-defined and continuous stratiform layers carrying sulphides of nickel, copper, and iron.

In the Main or " Merensky " horizon, of sole importance to-day, the band is a dark coloured mixture of hypersthene, bronzite, and a little feldspar with porphyritic crystals of diallage, and usually including a thin chromite layer, invariably over- as well as under-lain by light-coloured feldspathic varieties of norite and by anorthosite, all dipping in conformity with the " stratification " of the Lopolith. Below the oxidised zone the ore-bearer carries from 2 to 3 per cent. of sulphides, as small irregular grains in the silicates. The order of crystallisation was generally silicates, pyrrhotite, graphite, pentlandite, chalcopyrite, cubanite and most of the platinoids, followed by pegmatitic and pneumatolytic phases with iron-nickel sulphides and platinum arsenide, and finally hydrothermal alterations. Rutile and zircon may be present (Frankel). The platinoids are contained in the sulphides, but their proportions remain unchanged in the oxidised rock ; values range generally from 1 to 4 dwts., less commonly to 5 or 6, but only rarely as yet to over 10 dwts., the upper part of the band being commonly the richer.

In Rustenburg the Merensky horizon, from 3 to 6 feet thick, running with amazing regularity and dipping at from 12° to 16°, has been traced by pits through the black soil with some breaks—from Wolhuterskop past Rustenburg and Boshoek, west of the Pilansberg,

and thence north-eastwards to Swartkop. In the deposit on Kroonendal and Klipfontein just east of Rustenburg, actively worked by the Rustenburg Platinum Mines, the ore-body is 32 inches thick, which, after picking, averages 5·7 dwts. over the equivalent of 24 inches. The export for 1951 was 145,395 oz., valued at £3,405,542. The Union Platinum Mining Co. is actively developing Zwartklip No. 988 north of the Pilansberg, where the reef is estimated to average 6·3 dwts.

In Lydenburg this horizon ranges from 3 to 35 feet in thickness, dipping at angles from 10° to 40° (Fig. 22, 11c), following the curve of the basin for 100 miles from Diamant on the Olifants River along the eastern base of the Lulu Mountains through Paschaskraal, Winnaarshoek, Driekop, Maandagshoek, Eerstegeluk, across the Steelpoort River, up the Dwaars River, across Richmond, St Edmunds, and Booysendal, ending on Kliprivier. Parallel bands of similar character have been opened up on a horizon either higher or lower, *e.g.* on Kalkfontein and St Edmunds. Smaller irregular rather stratiform bodies of sulphide-bearing feldspar-rich norite occur in the upper part of the Norite, *e.g.* on Steelpoort Park in Lydenburg, where the platinum content ranges from 0·5 to 2·5 dwts.

In Potgietersrust, where the mineralised rock forms bodies of astonishing magnitude, the well-stratified norite-pyroxenite mass is dipping at a higher angle, from 20° to 60°, cutting diagonally through the Transvaal System (chiefly the Dolomite), large masses of which it envelops with extensive metamorphism and assimilation. Platinum occurs here on at least three horizons, the two lowest on Tweefontein. The " Merensky horizon " has been traced at intervals north-northwestwards from Potgietersrust for 25 miles to Dorstland, consisting of the usual diallage norite with rather low values. In the central section on Sandsloot, Vaalkop, and Swartfontein this horizon is replaced by extensive lenticular bodies of coarse feldspar-rich norite containing sulphides, swelling at one point to 146 feet and dipping at 55°, averaging 3 dwts. of platinoids. Farther to the north, running into Swartfontein, it ranges from 10 to over 20 feet with a value of from 2 to 20 dwts., and rests upon highly altered dolomite (calc-silicate) rocks which have been impregnated with sulphides to a depth in places exceeding 30 feet and assaying up to 16 dwts.

(2) *Contact Metasomatic Deposits.*—The last-named belongs to this type, in which magmatic liquids and gases have played a part. On Tweefontein in similar fashion crush zones in the banded ironstones underlying the Dolomite have been mineralised and carry copper, nickel, platinum, and sperrylite (arsenide of platinum) in splendent crystals.

These discoveries in the Bushveld are undoubtedly the world's greatest primary concentrations of platinum, the well-known occur-

rences in olivine dunite of the Urals being only workable on a limited scale because of the extremely small proportion of that metal in the ultrabasic rock.

In Southern Rhodesia [1] the Great Dyke contains at various places a dark sulphide-bearing band overlain, as in the Merensky horizon, by feldspathic norite. At Wedza in the Belingwe district the band is from 3 to 6 feet thick, assaying several dwts. Similar reports come from Selukwe, while to the north at Makwiro in the Darwendale district the zone is from 8 to 10 feet thick, running up to 6 dwts. The platinum is present mainly as finely divided sperrylite. Operations were suspended because of metallurgical difficulties.

In East Griqualand platinum occurs in the sulphide-bearing olivine norite at Insizwa, assays sometimes giving very high values.

(3) *Quartzose Veins.*—Extraordinary is the presence of this metal associated with specular iron-ore in brecciated quartz-veins of post-Karroo age traversing the Rooiberg Felsites on Welgevonden, Rietfontein, and Doornhoek to the north-east of Nylstroom, occasional high though erratic values having been found. Not improbably it has been derived from the norite that underlies the region.

Unique is a platiniferous breccia cutting Waterberg rocks on Mooikoppie (58) in the Middelburg district, having a matrix of quartz, diaspore, kaolinite, and specular iron-ore. The metal has also been reported in auriferous lodes cutting the serpentines and schists near Steynsdorp in the Barberton district.

(4) *Witwatersrand Conglomerates.*—Osmiridium in minute grains is recovered from the banket, more particularly on the East Rand, where the proportion ranges between 0·1 and 1 oz. per 1000 tons milled, the ore being richest about Brakpan. The output is about 7000 oz. annually, valued at nearly £250,000.

(5) *Alluvial Deposits.*—Placers that may perhaps be workable occur in the Steelpoort Valley near the railway bridge, on Diamant near Nylstroom, and on Swartfontein to the north of Potgietersrust.

Salt and Gypsum.—(a) *Salt.*—At a number of points along the Atlantic coast sand-dunes have shut off an arm of the sea and elongated salt-pans resulted therefrom. One close to Cape Cross is 8 miles long with a thick crust of salt. Others are at Swakopmund, Port Nolloth, and Ysterfontein Point near Cape Town.

Practically all the salt produced in the Union is got from *salt-pans* located in the drier areas. The majority are situated upon the Dwyka tillite or shales, from Calvinia right through to Dealesville and Christiana, also in Gordonia. A few are located on the older rocks,

[1] B. Lightfoot, *S. Rhod. G.S.*, 1926, Short Rep. 19; *ibid.*, 1927, Short Rep. 21; *P.G.S.S.A.*, 1941, xliii, p. xxvii.

e.g. Klein and Groot Chwaing (Stella) in Vryburg, while the three pans at Teviot near Hofmeyer stand on Beaufort beds and the Saltpan in the Zoutpansberg on Karroo basalt. For the Kalahari can be cited the Makarikari and Etosha pans.

They are due to the concentration within these depressions of traces of salt gradually leached out from the surrounding rocks. Favourable has been an appreciable surface catchment with an impervious floor, and more particularly an approach towards semi-artesian conditions, as at Salt Lake near Douglas. Commonly strong supplies of brine are found in them almost at the surface ; thus at Britten near Christiana about half a million gallons daily are being pumped from boreholes in the pan. Such reserves of salt must be considerable, seeing that many of the larger pans have been worked on a large scale for years without definite signs of exhaustion, but this problem is deserving of closer study.

In the Zwartkops and Bethelsdorp Saltpans near Port Elizabeth the salt has probably been derived from saline strata in the Uitenhage Series. The Matsap Pan in Griqualand West, which is underlain by dark Karroo shales carrying fish-remains, is interesting in that potassium nitrate (saltpetre) has been found in appreciable quantities in the brine,[1] more especially in the lower layer, proved by boreholes ; this substance may have been produced by nitrifying organisms in the soil. The large proportion of carbonate of soda in the Saltpan north of Pretoria has been referred to elsewhere (p. 427).

(b) *Gypsum.*[2]—Sulphate of lime is commonly present as crystals or aggregates in the clays flooring salt-pans or flats, as at Gannavlakte near Windsorton Road Station. It has largely been due to oxidation of pyrite in Karroo shales—particularly the White Band—or pre-Cape slates, as near the Hol River in Van Rhynsdorp. For the coastal pans sea-spray may have contributed. The pans are furnishing all the output required, chiefly in cement manufacture, the problem being to recover the more finely divided mineral.

Silver.—Although the production of silver in the Union has for years exceeded a million ounces annually, practically all comes from the Rand mines, since it is alloyed with the gold to the extent of about one-tenth. Most of the galena deposits contain a good proportion of silver and such have been worked east of Pretoria or at Argent on the Germiston-Witbank railway, or else obtained as a by-product from gold ores, as at the Falcon Mine (Umvuma) and Lonely Mine (Bubi) in Rhodesia, and at Penhalonga near Umtali, which has produced more than four times by weight of silver than gold, and nearly all Southern Rhodesia's lead output.

[1] H. O'K. Webber, *S.A.J.I.*, 1922, v, 265.
[2] B. Wasserstein, *Union S.A.G.S.*, 1935, Bull. 3.

Tantalum.—Tantalite and columbite occur as large crystals in pegmatite near Steinkopf in Namaqualand, throughout the Erongo tin-fields of South-West Africa, at Palakop in the Letaba area, in the Bubi and Victoria districts, and with cassiterite and lithia-mica in the greisens of the Odzi and Tsungwesi Reserves near Umtali, and as simpsonite at Bikita, east of Fort Victoria (Macgregor).

Tin.—During the past few decades this country has become quite an important producer of tin, cassiterite having been found in several widely separated areas, invariably within or in close association with granitic rocks, more particularly those of the younger (post-Transvaal) group.

(*a*) The outputs from the alluvial deposits at Kuils River in the Cape Peninsula, of Mbabane (Embabaan) in Swaziland, the adjoining section of the Transvaal (Forbes Reef and Oshoek), and of the Karibib region of South-West Africa have been considerable, the cassiterite in those concentrations having been traced up to occasional veins of pegmatite, greisen, and quartz in the granite or in the contact-zone of slates and schists with the latter, but which in the two first-mentioned regions are not in themselves rich enough to be worked. Numerous tin-bearing pegmatites in schists have been discovered in the neighbourhood of the conspicuous granite masses forming the Erongo Mountains, Spitzkop, Brand Berg, Paukwab Mountain, etc., those at Otjimboyo due east of Erongo Station and at the Pieterhill south-west of the Erongo being actively worked.[1] Long pegmatite dykes with tinstone, wolframite, or tantalite in para-gneiss near Tshontanda Station in the Wankie area form the most important source in Southern Rhodesia, but in the Enterprise area near Salisbury,[2] in Mazoe to the south of the Shamva, at the Sequel Mine, Bikita, to the east of Fort Victoria, and again at Doeroi Station in Manicaland, there are similar types of reefs, which are encouraging although the ore is distributed erratically in them.

(*b*) In the middle of the Bushveld region of the Transvaal [3] there are five principal mining centres, namely Stavoren in the south-east, Leeuwpoort, Nieuwpoort, Swartkloof, and Rooiberg to the west of Warmbaths, and particularly Zaaiplaats to the north-west of Potgietersrust, with a host of minor localities at which prospecting has been conducted and from which smaller amounts of tin have been

[1] T. W. Gevers and H. F. Frommurze, *T.G.S.S.A.*, 1929, xxxii, 111.

[2] H. B. Maufe, *S. Rhod. G.S.*, 1920, Bull. 7.

[3] H. Kynaston and E. T. Mellor, *The Geology of the Waterberg Tin Fields*, Union S.A.G.S., 1909, Mem. 4; P. A. Wagner, *The Mutue Fides-Stavoren Tin-fields*, Union S.A.G.S., 1921, Mem. 16; W. J. Gau and J. J. Jameson, *Third Emp. Min. Congr.*, 1930, iii, 197; *Min. Res. Union S.A.*, 1940, 293; P. G. Söhnge, *T.G.S.S.A.*, 1945, xlvii, 157; L. G. Boardman, *ibid.*, 1947, xlix, 103.

recovered—Enkeldoorn, Doornhoek near Nylstroom, etc. The irregularity of the mineralisation has led to the investigation of the smallest veins, for in not a few instances such work has disclosed profitable ore-bodies in depth.

The workings follow very closely the upper contact of the intrusive Red Granite, the deposits being found either in the several varieties of that rock—in the latest phase thereof at Zaaiplaats—or in the overlying Rooiberg quartzites and felsites, the richest deposits being connected with up-arched portions of the " roof." They are the product in part of solutions, in part of gaseous emanations from the acid magma, which have (1) followed joints and planes of stratification in the Rooiberg Beds, (2) proceeded along lines of fissuring in, or (3) taken tortuous and restricted paths through, the granite and granophyre producing the extraordinary lodes known as " pipes." Some of these fissures, though certainly constituting channels for the passage of the mineralising agents, do not themselves carry ores.

In the first two cases mentioned, narrow, well-defined veins and large impregnations, more or less irregular, though frequently following the bedding planes—and therefore tabular—have resulted, with tendency towards the development of " pockets " at the intersection of two or more fissures. At Leeuwpoort, Nieuwpoort, and Rooiberg the ore is confined mostly to quartzitic strata below the " Main Shale " and related to strong faulting, brecciation and tourmalinisation, the intersecting fissures making in places a stockwork. The connection with the granite beneath is not obvious, in contrast to the other occurrences along the granite-felsite boundary in this quarter. The cassiterite is invariably associated with tourmaline, hæmatite, pyrite, and sometimes chalcopyrite, and would seem to be restricted to relatively shallow depths.

The pipes form striking features in the several fields, though of little importance to-day, and, with but few exceptions, are restricted to the granite and to pegmatite veins in the earlier granophyre. They are particularly well developed at Zaaiplaats where, as groups, they have been followed downwards, in some cases for 3000 feet, twisting, uniting, and branching along their courses, but possessing a rough common dip, which may be as low as 15°. They range from a few inches up to 40 feet across and are approximately cylindrical or oval in cross-section (Fig. 73), though subject to considerable variation in size and outline at different levels. Characteristically they exhibit a distinct zonal structure. In one type an ore composed of red or pink feldspar and cassiterite has been formed by replacement of the quartz of a fine or coarse granite; in another this feldspar has in turn been replaced by sericite, calcite, chalcedony, etc. In those at Zaaiplaats there is an outer ring of black tourmaline filled with a greisen-like rock carrying cassiterite, but containing patches or druses of calcite and fluorite,

sulphides, and other minerals ; at Stavoren the outer border is generally a black lithia-mica, while tourmaline is absent. At Zaaiplaats numerous small " pods " have latterly been discovered ; also disseminated, though payable, ores in granite that has been invaded by its final phase, as well as in certain zones in the latter (Söhnge).

The minerals associated with the tin in these fields are usually chalcopyrite, pyrite, and arsenopyrite, sometimes wolframite, scheelite, molybdenite, galena, and zincblende. Features have been observed in the Stavoren deposits that appear to indicate a dependence of lode-content on the temperature of its formation, and pneumatolytic and hydrothermal phases have been distinguished that can be correlated with the progressive cooling in the lodes. Thus, the deposits formed in the granite (at highest temperature and pressure) are essentially stanniferous ; those in the overlying granophyre (at lower temperature

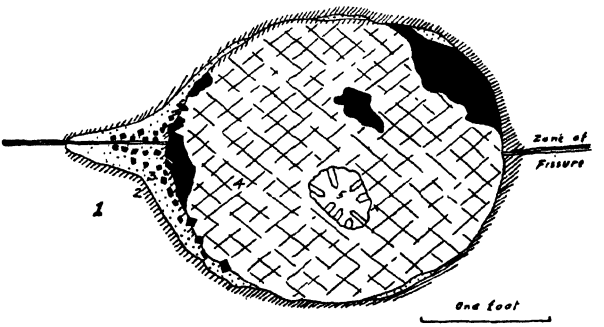

FIG. 73.—Section through Tin-bearing " Pipe " in Granophyre, Stavoren. 1, Granophyre ; 2, Black Mica ; 3, Red Feldspar ; 4, Fluorspar ; 5, Druse with Quartz Crystals ; Black, Ore-minerals—Cassiterite, Arsenopyrite, Chalcopyrite, and Scheelite. (*After* Wagner.)

and pressure) carry tungsten and copper ; those in the succeeding Rooiberg Beds contain iron as well.

Tungsten.—The two chief ores Wolframite (tungstate of iron and manganese) and Scheelite (tungstate of lime) are widely distributed, though mostly in small amounts, but rarely together, as (1) irregular pockets in acid pegmatite, aplite, and quartz—chiefly as wolframite—*e.g.* north of Essexvale Siding on the West Nicholson railway in Southern Rhodesia, and associated with tin near Tshontanda Station in the Wankie area, at Nakeis to the south-east of Klein Karas Station and at Omaruru in South-West Africa, in the Steinkopf Reserve in Namaqualand, at the Collins Mine on the Orange River next the South-West border, at Daberas and Oup in Kenhardt, and—as scheelite—near Steinkopf ; (2) in gold-quartz veins in granite—principally as

scheelite together with sulphides—*e.g.* at the Scheelite King Mine and —as a by-product—at the Golden Valley Mine near Gatooma, at Umtali, at Essexvale, near Gwelo, on the Bembesi River, at Bikita near Fort Victoria, Stromboli Mine at Leydsdorp, and near Barberton; (3) in copper ores, *e.g.* Lomagundi, and in tin ores, *e.g.* Stavoren and Rooiberg in the Bushveld; and (4) in veins with chalcopyrite in Karroo basalt close to the later granite at the Hippo Scheelite Mine on the left bank of the Sabi River in the south-eastern corner of Rhodesia.

Vanadium.—This rare and valuable element is present as Vanadinite (chloro-vanadate of lead) in the lead deposits on Kaffirskraal and Doornhoek in Marico in veins cutting the Dolomite, which has here been converted into a soft manganiferous earth. The ore, which is of secondary origin, is found as irregular layers, veins, or incrustations along with pyromorphite, cerussite, and galena. The deposit on Kaffirskraal is bounded by two igneous dykes with which it is almost certainly genetically connected.

In South-West Africa superficially concentrated ores are found in sand and rubble-filled solution cavities in the Dolomite at Tsumeb and several other places in the Grootfontein district, for example in brecciated dolomite forming a pipe-like mass at Abenab and a reef-like body at Abenab West adjoining, the minerals consisting chiefly of mottramite (copper-lead vanadate) and descloizite. The production for the two and a half years 1945-7 was 9231 tons, valued at about £20 per ton, but in 1951 production had fallen to 2763 tons of vanadium-lead concentrates. In addition the zinc-lead mines of Broken Hill, Northern Rhodesia, produce large amounts of vanadium ores. The titaniferous-magnetite deposits of the Bushveld and Rooiwater Complex, etc., contain some vanadium, and it was indeed proposed to work those in the Tugela Valley near Kranskop, which carry about 0·74 per cent. of vanadium oxide as iron vanadate.

Vermiculite.[1]—This remarkable micaceous golden-yellow mineral, of rising industrial importance because of its property of expanding greatly when heated, occurs as an immense concentration in the pyroxenite and serpentine body of Palabora in the eastern Transvaal (p. 63), largely with apatite, as masses, lenticular bodies, pockets, and disseminations. It appears to pass in depth into phlogopite mica, from which it has seemingly been derived, and is accompanied by black iron-rich hydrobiotite (Gevers). The quantity is said to be enormous. Production is increasing, the value being roughly £5 per ton.

The mineral is also found in an identical setting at Dorowa in the Upper Sabi Valley, Southern Rhodesia (p. 409).

[1] C. M. Schwellnus, *Union S.A.G.S.*, 1938, Bull. 11.

Water.—An uncommonly large proportion of this country is without supplies of surface water except for a limited period during the rainy season, while perennial streams are few. Although advantage has been taken by the settler of springs and shallow wells, it is through boring that the salvation of South Africa has been effected. Wide regions in South-West Africa, Bechuanaland, and the south-western and northern Transvaal have been opened up almost entirely by means of the drill, and vast areas still await their turn. Recently considerable benefits have followed the use of geophysical methods of water-location.

A. SPRINGS. *Warm Springs.*—In addition to a multitude of cold springs there are a considerable number of warm ones with various temperatures. The Zongola Geyser and the Kapesa Hot Spring within the Zambezi trough, not far from the junctions with the Gwaai and the Sanyati respectively, yield water at 206° F. and 133° F., but the majority range between 70° and 90° F. Some of them are perfectly fresh, others are highly mineralised, while they are generally not connected with any particular formation, nor confined to any special belts of country, nor closely associated with recent volcanic rocks. With few exceptions those furnishing sulphuretted waters issue from beds of the Karroo System, *e.g.* Aliwal North, or Bokkeveld, the gas being derived from pyrite or marcasite in the strata.

In regard to their location many appear at the junction of dissimilar formations, the contact surface making a water-plane. The warm springs at Caledon, Warmwater Berg, Montagu and Olifants River (Oudtshoorn) issue on the flanks or ends of anticlinal ranges, where the Table Mountain sandstones pass beneath the Bokkeveld slates; that at Brandvlei, Worcester, has a temperature of 147° F. Frequently they have been determined by igneous dykes or inclined sheets, as is indeed most common throughout the region occupied by Karroo beds and intrusive dolerite. At other times a line of faulting has been responsible, as in the six hot springs (up to 175° F.) [1] which provide the town of Windhoek with its supply (in mica schist), at Kuibis (in quartzite and limestone), Warmbaths in the Transvaal (in Red Granite), Tugela Ferry, and Lilani near Greytown in Natal [2] (in amphibolite), the Letaba River (106° F.) (in Old Granite) and Loubad near Nylstroom [3] (in Waterberg). Connected with post-Karroo fault-lines are most of the Rhodesian springs, many of them warm, for example those within the broad belt trending north-eastwards from Wankie down the Zambezi.[4] In other cases, however, there are no obvious structural features with which they can be correlated, *e.g.* Warmbad in South-

[1] For details see T. W. Gevers, *T.G.S.S.A.*, 1933, xxxv, 1.
[2] T. W. Gevers, *T.G.S.S.A.*, 1943, xlv, 43.
[3] L. E. Kent, *T.R.S.S.A.*, 1942, xxix, 35.
[4] See H. B. Maufe, *S. Rhod. G.S.*, 1933, Bull. 23.

West Africa and Badplaats east of Carolina (in the Old Granite), Machadodorp (in diabase), and Aliwal North and Tarka Bridge near Cradock (in Karroo beds).

At the last place saline water at a temperature of about 80° F. issues from four shallow boreholes and, most remarkably, its level rises and falls at twelve and a half hour intervals as with the oceanic tides. The boreholes clearly draw their supplies from the same underground source, for the composition and temperature is the same in all, while the pumping of one hole affects the discharge from the others.

(2) *Cold Springs*.—The Dolomite is responsible for the cold ones in South-West Africa, the Transvaal, and Griqualand West, while several large open sink-holes are known with standing permanent water, *e.g.* the Wondergat just east of Mafeking, Lake Otjikoto near Tsumeb, and Sinoia Cave.

The water may appear just above the Black Reef, as at the " eye " of the Mooi River or at Ventersdorp, or at its contact with the underlying granite, as at Motiton, west of Vryburg ; where the dolomite dips beneath the Pretoria beds, as at Steenkoppies west of Krugersdorp and at Pretoria ; above syenitic dykes, as in the Wonderfontein Loop between Randfontein and Potchefstroom. As is so common in limestone regions, the springs may issue from solution-channels without any relation to structural or other features, as in the Molopo Eye in Marico, at Kuruman and at Otavifontein in South-West Africa ; minor examples of such are abundant. The larger springs in the Dolomite are rather constant in their yields, with outputs of from 4 to 13 millions of gallons per diem, though the discharge may lag behind the rainfall by from six months to two years ; the biggest is the Gerhardminnebron near Potchefstroom. These waters are naturally charged with carbonates of lime and magnesia, the proportion of such solids ranging from 14 to 24 parts per 100,000, with an average of 20, the pH value ranging from 7·0 to 8·0. The Newlands and Albion Springs near Cape Town emerge along a fault-line in slates. Those at Kokstad, from dolerite, yield about a million gallons daily. Fresh water issues during low tides at Osterwal in Saldanha Bay and at the mouth of the Coega River.

B. Wells and Boreholes.—*Truly artesian* supplies are all but confined to two regions.

To the north-east of Mariental in South-West Africa a number of boreholes from 300 to 600 feet deep sunk along and outside the dry troughs of the Auob River around Hofmeyr and Stampried, and of the Nossob above and below Pretorius, yield huge flowing supplies of good quality, the water-horizon belonging to the Karroo System and consisting of beds of porous sandstone averaging from about 50 to 175 feet thick sandwiched between blue shales.

Quite a number have gushed at the rate of over half a million gallons per day, and a couple—Osterode and Nabas—at about three-quarters of a million, while static pressures up to 32 lb. to the square inch have been measured; the outputs are, however, being controlled by stop-valves, since some large decreases have already been observed. There are also many non-flowing holes. The intake is mainly the ground sloping southwards from the base of the ranges between Rehoboth and Gobabis. The "aquifer" or artesian stratum is dropping gently towards the south-east, the limit of the basin down the Nossob being 30 miles from the Cape border.

Another artesian area exists in the north, the borehole 532 feet deep at Andoni on the northern side of the Etosha Pan furnishing about half a million gallons a day at nearly 30 lb. pressure.

In the Uitenhage district porous pebbly sandstones of the Cretaceous have a sporadic development, filling hollows in the Cape rocks and dipping beneath the Variegated Marls (see p. 378). A number of boreholes in the Elands Valley close to Uitenhage yield flowing supplies, but unfortunately of water rather high in mineral matter, notably sulphate of iron from pyrite or marcasite in the water-bearing beds. At Zwartkops water issuing from this zone at a depth of 3600 feet with a temperature of 130° F. is chalybeate and valuable medicinally. At Balmoral, near Uitenhage, the water pours out at from 200,000 to 300,000 gallons a day from boreholes piercing the jointed Table Mountain Sandstone beneath the impervious covering of Cretaceous clays. Flowing holes occur on Disco near Addo and Klipfontein in Baviaans Kloof.

The Springbok Flats has been regarded as a possible artesian basin and certainly possesses the requisite structure; on the other hand, the "intake" on the north may be insufficient, the beds themselves are not conspicuous for permeability, and there are certain concealed ridges, which might interrupt the movement of water along the bottom of the basin. Such a barrier was struck in the 1564-feet borehole on the farm Diepsloot, while practically all the other deep borings, from 500 to over 800 feet, have given only limited pumping supplies.

There is even less reason for supposing that the Great Karroo constitutes an artesian area. The porosity of the sandstones is very low, while the formation is intersected by a maze of dolerite intrusions, which would act as barriers to underground circulation.

With regard to ground-water generally there is commonly no real "water-table," for the reason that owing to the lack of pervious strata the underground water circulates mainly by means of the bedding-planes, joints, and fissures in the rocks and consequently in, or just below, the zone of weathering; this explains why there are productive wells even in solid granite and other crystalline rocks. The supply in all cases is maintained by infiltration from the annual rainfall and is

usually of local and not far-travelled origin, but the extraordinary feature is that the yields are to so great an extent almost independent of the magnitude of the seasonal precipitation. There is, for instance, less difficulty in obtaining water in the semi-arid Karroo, say about Laingsburg, Willowmore, Cookhouse, etc., than over much of the Transvaal or Natal with treble the rainfall. Apparently the more clayey character of the soils as developed in the wetter region tends to prevent the ingress of the surface waters as freely as in the drier one. In the case of the flat-lying Dolomite near the Rand with its covering of absorbent sand the infiltration amounts to as much as 11 per cent. of the rainfall, but on other formations this coefficient, and consequently the yield, must be much lower. When the rocks are foliated, tilted, or cleaved, so that the ingress of rain water is facilitated, the yields are usually higher than when they are homogeneous or flat-lying. Consequently the gneisses, cleaved greenstones, and phyllites, are better producers than the massive granites, felsites, quartz porphyries, epidiorites or amphibolites, and the tilted Pretoria beds or jointed Dwyka tillite than the horizontal Karroo strata. Quartzites, though hard to drill, often furnish satisfactory supplies, *e.g.* the Timeball Hill Group of the Pretoria Series. In the amygdaloidal diabase of the Ventersdorp System or the Ongeluk (Pretoria) lavas drilling is comparatively easy and the yields generally satisfactory.

In the great dry sandy region of the Kalahari the scanty groundwater is so held by the deep sand that it is not generally available for collection in wells. Where the covering is shallow, say up to about 100 feet, water can generally be got without much difficulty in the underlying formation, for example in Mafeking, Vryburg, Gordonia, Keetmanshoop, etc., in the Granite, Nama, or Dwyka Series; with a thicker covering the results are more variable. Many boreholes in the porous Kalahari limestone and sandstone have been successful, as for instance along the lower Auob or the lower Kuruman River, but others in Bechuanaland to the north-east and west of Kuruman have penetrated the red marls, and a goodly proportion have been failures.

The *contact* of two dissimilar rocks is frequently a water-plane, either (1) an unconformable one upon an older formation, *e.g.* the base of the Dwyka Tillite or Black Reef or Alexandria limestones, (2) a lithological discontinuity, *e.g.* a sandstone bed on shale or a band of slates on quartzite, or (3) an igneous contact, *e.g.* those of the numerous diabase sheets of the Pretoria Series or of dolerite in the Karroo, both the upper and lower boundaries being commonly available, though the former is the better generally. It has been a kind of unwritten law to avoid drilling in dolerite or diabase yet, with the aid of heavier drills, such intrusions are nowadays repeatedly being pierced or bored into for some distance and water obtained. The underflow is intercepted by the more dyke-like intrusions in the gneisses or sediments and may

be even brought up to the surface as a spring. Boring behind (above) such barriers is commonly successful and is the general policy in the Karroo region; even in the case of hard crystalline rocks such as granite the presence of such dykes has been of advantage, more particularly in Rhodesia. The kimberlite dykes and pipes give large and usually shallow supplies. As a rule, the deeper the weathering of the rock the better the supply; the worst producers in the Union are the Bushveld norite and red granite—both rather " solid " formations. In the dolomitic groups, on the contrary, the rock itself is practically impervious, the water travelling along solution joints and fissures, consequently the yields are erratic.

Depth.—In much of the Karroo, the folded belt and south-west of the Cape, the Orange Free State, and south-western Transvaal shallow holes are the rule, water being struck at from 40 to 100 feet, rising thereafter to a certain distance in the borehole. In the Coal Measures of the south-eastern Transvaal about 150 feet is usual; but in the Old Granite of the Transvaal and of Rhodesia from 150 to 200 feet is common, while in the Koranna Berg and north-west Mafeking over 250 feet is almost the rule and up to 300 feet frequent.

After the general depth for the district or formation is exceeded, a falling-off in yield is to be found. It is rather rare to have good supplies furnished by holes well in excess of the average depth, say from 300 feet onwards, because the rocks have become more solid down below; progressing beyond 500 feet can hardly ever be recommended, a second trial elsewhere being usually more satisfactory. Of those exceeding 400 feet the majority derive their supply in great part from the upper strata or are low in their output; as stated earlier, the lack of porosity militates against the presence of deep-seated water in synclinal or monoclinal structures in this country.

Yields.—In the majority of formations the successful holes give on test anything up to about 30,000 gallons per day but, where the conditions are more favourable, up to 80,000 may be obtained; instances of over 100,000 are distinctly uncommon. In the Dolomite, even under continuous pumping, some large yields have been got, *e.g.* in the Klip River Valley and at Zuurbekom near Johannesburg—up to a million or more gallons from a well or large diameter borehole. The artesian flows in South-West Africa have already been cited.

Salinity.—To a large extent this character is dependent on the local rainfall, climate, and topography, consequently the prevailing salinity of the waters at such places as Walvis, Lüderitz, and Saldanha Bay is only to be expected. Siliceous formations tend naturally to yield fresh waters in the majority of situations, for example the Table Mountain Sandstone, Molteno beds, and most granites and gneisses. The Table Mountain Sandstone yields " acid " waters with a pH value of 4·5 to 6.

The Bokkeveld and Malmesbury slates furnish brackish waters, which in the case of the latter are frequently rich in magnesium salts. From the fact that in the west and north of the Cape and in South-West Africa the bulk of the saltpans are located on the Dwyka tillite or shales, it will not be surprising to learn that the water in wells in those particular formations is generally brackish, high in sulphates, and often undrinkable. In Natal, on the contrary, the tillite, though not so productive, is only slightly saline. The waters of the Lower Beaufort beds contain some chlorides, but those of the Middle and Upper divisions are distinctly alkaline owing to sodium bicarbonate and may have pH values as high as 6·2. The supplies from the Uitenhage beds in the Oudtshoorn and Uitenhage districts are frequently very salt and sometimes charged with sulphate of lime or of iron. The waters from the Dolomite contain merely carbonates of lime and magnesia, in the proportion usually from 14 to 24 parts per 100,000, which confer on them " temporary hardness " ; those from the Ventersdorp lavas not uncommonly carry a fair amount of carbonate of lime also, and naturally the same would be the case in the Kalahari or Alexandria limestones.[1]

Zinc.—See Lead.

[1] Further information will be obtained in the following papers :—

A. L. du Toit, " The Geology of Underground Water Supply," *Min. Proc. S.A. Soc. Civil Eng.*, 1913, 7 ; " Porosity of Rocks of the Karroo System," *T.R.S.S.A.*, 1915, iv, 169 ; " Borehole Water Supplies in the Union of S.A.," *Min. Proc. S.A.C.E.*, 1928, xxvi, 74.

E. Kaiser and W. Beetz, " Die Wasserschliessung in der südlichen Namib," *Zeits. Prakt. Geol.*, 1919, xxvii, 165.

H. B. Maufe, " The Geology of Underground Water in South Rhodesia," *Proc. Rhod. Sci. Assoc.*, 1921, xix, 23.

M. Rindl, " The Medicinal Springs of S.A.," *S.A.J.S.*, 1917, 528 ; *ibid.*, 1918, 217.

H. F. Frommurze, " Flowing Boreholes in the Gibeon, Rehoboth and Gobabis Districts, S.-W. A.," *T.G.S.S.A.*, 1931, xxxiv, 129 ; " The Water-bearing Properties of the more Important Geological Formations in the Union S.A.," *Union S.A.G.S.*, 1937, Mem. 34 ; " Scientific Methods of Water Finding," *P.G.S.S.A.*, 1944, xlvi, p. xxiii.

F. Dixey, *A Practical Handbook of Water Supply*, London, 1931.

G. W. Bond, " A Geochemical Survey of the Underground Water Supplies of the Union of S.A.," *Union S.A.G.S.*, 1946, Mem. 41.

CHAPTER XXI

THE GEOLOGICAL HISTORY OF SOUTH AFRICA

The Dawn of History.—Just as in the case of all other countries, the earliest pages in the geological record of South Africa are fragmentary and utterly confusing; only the outlines have been reconstructed. It must suffice to remark that, *certainly more than* 1500 *million years ago*, basic lavas—seemingly the earliest known of the rocks—were being poured out over several large sections of this country, in many places sub-aqueously—probably upon the ocean floor—that they were accompanied and followed by tuffs, slates, limestones, and the remarkable group of the banded ironstones, jaspilites, and cherts, and by quartzites, grits, and conglomerates.

This conjecturally *primitive crust* to the Earth was rent by vast protrusions of granite and gneiss, which crumpled up and highly metamorphosed the shattered remnants, producing banded "ortho-" and "para-gneisses," granulites, and schists of various kinds on a huge scale, which were then pierced by younger stocks of granite derived very probably from the same magma.

Some of the formations appear to have been laid down in the ocean, others are more probably of continental origin, while glacial conditions can be deduced for more than one Series.

Correlation with the *Primitive Formations* of other countries, based largely on lithological characters, is difficult since certain kinds of sediments met with are of types that have been laid down repeatedly during the Pre-Palæozoic and cannot be said to characterise one particular period; such is the case with the banded ironstones for example. Attention should, however, be drawn to the remarkable lithological parallelism with the rocks of the Dharwar System of India, particularly their development in Mysore State, those of Western Australia and of eastern Brazil. The first two countries display an abundance of granulites, greenstones, epidiorites, and banded ironstones. It is not unlikely that these four countries were already connected, seeing that they were apparently united at the beginning of the Devonian. They are also in agreement in that the intrusion of the batholithic granites led in each case to an extensive mineralisation of the invaded formations and to the production more particularly of *auriferous lodes*.

That the ancient complexes of South Africa were the products of several geological revolutions is clearly indicated by the existence of conglomerate beds crammed with pebbles derived from still earlier

rocks and from the *granitic intrusions into them*—and by the detection of strong unconformities between these pristine groups of the era known as the *Ep-archæan*, as set forth in Chapter III.

The Witwatersrand System.—We are on safer ground on coming to treat of this formation, so notable a contributor to South Africa's prosperity. The worn-down southern part of the Transvaal and northern part of the Orange Free State were invaded, apparently from the south-east, by a shallow sea in which were deposited gravels, sands, and muds—the latter frequently ferruginous—though no limestones. The pebbles of bluish and dark quartz, quartzite, quartz porphyry, jasper, and banded chert are all such as could have been furnished by the Primitive Systems of Bechuanaland, Rhodesia, or eastern Transvaal with their many veins of frequently auriferous quartz. Glacial conditions persisted for a time, while volcanic outbursts took place now and again.

About the middle of the period shallowing led to the production of extensive beaches and delta-flats, upon which river-systems, descending from the north and north-west, discharged sands and pebbles. Associated with the gravels were auriferous " black sands " containing hæmatite, magnetite, ilmenite, chromite, zircon, and iridosmine—like those forming " placers " in certain parts of the world. From time to time thin layers of pebbles, along with heavy mineral concentrates, were spread out in regular sheets, occasionally channelled by shallow stream-courses, the " shoots " or " pay-streaks " representing apparently drowned pebble-beaches. Following burial beneath further materials, their iron minerals were converted into pyrite, the particles of alluvial gold recrystallised, and the sands changed into quartzites and the gravel-beds into " bankets," an action that must have been accomplished quite soon, since pebbles of banket are to be found in certain of the succeeding Ventersdorp conglomerates.

In the meantime elevation was in progress in the north and north-west, with the result that to the north of the Rand and west and south of Klerksdorp the previously deposited Lower Witwatersrand beds were tilted up and eroded and an abundance of coarse material discharged south-eastwards to build up the pebble-beds of the Elsburg Series.

The basin within which gold-bearing waste was spread was exceptionally large—at least 170 miles long, and, if the Pongola System be included, well over 300 miles. Considerable portions lie concealed beneath younger formations.

Whether the Witwatersrand System has its representatives elsewhere in or outside of this country is not assured, though it is paralleled by the Tarkwaian System of Gold Coast and Nullagine of Western Australia, while the presence of diamonds of detrital origin in the

banket recalls the similar occurrences of that gem in conglomerates in the Vindhyan System of India and Lavras Series of eastern Brazil.

The Ventersdorp Eruptions.—The dictum that prolonged sedimentation is terminated by volcanicity finds a good example in the vast effusions of the Ventersdorp System. Over the Rand-Parys area they terminated Witwatersrand sedimentation and appear conformable thereto, but elsewhere the lavas—and occasionally agglomerates—were poured out over a surface of eroded Witwatersrand or more ancient rocks, probably land for the most part. Local basins of sedimentation are indicated by boulder-beds, grits, sandstones, etc., that preceded or accompanied the effusions, as particularly around Odendaalsrus, in the centre of the Mafeking district, at Omdraais Vlei near Britstown, along the Orange River valley above Upington, and in the areas occupied by the Konkip Series in South-West Africa. In addition to the eruption of andesitic and basaltic lavas, acid types were poured out and breccias and tuffs formed, also intercalations of various kinds of sediments. As is usual with formations composed principally of eruptive materials, rapid variations in character and thickness and local unconformities are not uncommon.

During and also following these eruptions came a further tilting-up of the buried Witwatersrand formation to high angles, accompanied by thrusting on a considerable scale, the fracture lines striking east-west on the Central Rand, but curving towards the south-west in the section between Roodepoort and Randfontein, of which we have a good example in the "Witpoortje break," and continuing well beyond Klerksdorp. Indeed, allowing for a fair amount of tilting and faulting experienced in post-Transvaal times, the structure on the Rand was largely fixed by the end of this period; many of the numerous basic dykes were furthermore introduced at about this time.

The internal stresses having been relieved in these ways, the crustal movements died down and South Africa entered upon one of those periods of relative stability of the time-value of which, like the pre-Witwatersrand or the post-Waterberg-Matsap breaks, we have no real idea.

The Transvaal and Nama Marine Submergences.—During the intervening period, inferentially an extremely lengthy one, the country underwent a vast amount of erosion, whereby the greater part of the land area became worn down to a flat surface. That this huge area then subsided beneath the ocean, either as a whole or in two sections—depending upon whether the Transvaal and the Nama were synchronous or not—cannot be doubted, it being likely, too, that the thick and extensive limestone formations of Katanga, Angola, and Lower Congo were contemporaneous. If so, then towards the close of the pre-

Cambrian such subsidence brought about practically the complete reversal of the respective areas occupied by land and sea. Only in *two* subsequent epochs did the ocean trench upon the continent, namely during the Devonian over the southern half of the Cape Province, and in the Cretaceo-Tertiary, though merely along the continental margins.

Assuming contemporaneity,[1] the arenaceous basal beds (Black Reef, Nuwerus, etc.) represent inshore deposits laid down as the waves advanced over the peneplain, the thicker and generally coarser nature of which in the north-east of Lydenburg to the east and in the Maltahöhe district to the west indicate the presence of land areas in those two directions, while the puny development and more argillaceous habit along the Lower Vaal River suggest shallower water. With subsidence of the floor and retreat of the land-margins, shales and limestones accumulated, a purely carbonate phase—the Dolomite—prevailing over the Transvaal, northern Free State, Griqualand West, and Ovampoland (which we can suppose to have been covered by deep sea, one perhaps with warm waters), while a mixed argillaceous and calcareous phase prevailed in the Lomagundi district of Rhodesia and over the region extending from Windhoek southwards to the Cape and eastwards to Port Elizabeth at least. Where the limestones were best developed, their dolomitisation was most thorough, while the presence of manganese in them recalls the modern deep-sea oozes. Many of the limestones were apparently built up by algal life.

Shallowing of the Ocean.—Sedimentation having finally overtaken subsidence, a series of dark shales and white quartzites were laid down in the *Transvaal*, in shallow water as disclosed by the false-bedding, ripple-marks, and sun-cracks in the quartzites. Indeed, the local emergence of the top of the newly formed Dolomite in this Province has to be presumed because of the chert-conglomerate and the peculiar quartzite upon which the Pretoria beds rest. The detritus was furnished by a land-mass situated apparently to the north and east, one subject to a high rainfall and possessing probably a cool climate—the glacial horizon in the Daspoort Group should be remembered in this connection.

In the southern and south-eastern part of *South-West Africa* on the other hand the succeeding red sandstones and shales and grey quartzites of the Fish River and Zwart Modder beds suggest proximity to a land with a warmer climate, possibly one with a medium or low rainfall, under which oxidation of the rock-waste was general. Among the sediments deposited were ferruginous (magnetite) sands, while the cross-bedding in the red and striped sandstones points to strong

[1] The contemporaneity of the Transvaal and Nama systems is not accepted by many South African geologists (Editor).

currents and probably to wind-action, ripple-marking being common; possibly the area consisted of a wide tract of saline "shotts." [1]

Between these two regions of contrasting facies lay that of *Griqualand West and Bechuanaland*, wherein curious finely divided, highly ferruginous muds were dropped, evidently in quiet and fairly deep water, as signified by the marvellously close and even banding and the general absence of any but fine-grained material, except at a few localities on the south and west; there is, moreover, no break here with the Dolomite and chert group below. Their nearest modern representatives are apparently the red and blue terrigenous muds of the moderately deep parts of the ocean, but it seems not unlikely that chemical precipitation played an important part during their formation, as the high iron-content would suggest; indeed, the introduction of the sodium necessary to the formation of the mineral crocidolite is hard to explain except as a secondary chemical process. That similar conditions must temporarily have extended themselves into the Transvaal is borne out by the considerable development of banded ironstones at the top of the Dolomite and occasionally on higher horizons as well.

Glacial Interludes.—In view of still earlier glacial formations, such as the "Chuos Tillite" of South-West Africa, it occasions little surprise to find evidences for glaciation on several levels during this particular period, such as near the base at Nabas on the Lower Orange River, near the bottom of the limestones in the Karas Mountains and well up in the latter in the Otavi area, and the minor occurrences, due probably to floating ice, in the Pretoria and Griquatown Series. The number of observed glacial stages renders it indeed difficult to make correlation with the several widespread tillites in Katanga, Angola, and Lower Congo.

Eruptive Cycles.—The prolonged subsidence of the region resulted in several brief and widely separated periods of eruption. The first, closely following the glaciation, produced andesitic lavas and tuffs—the Ongeluk Volcanics of the Transvaal and Griqualand West, the flows being in part sub-aqueous, as denoted by the occasional development of "pillow structures" with chert filling in the interstices between the pillows, exactly as the Palæozoic radiolarian cherts behave in other countries. The two subsequent occasions gave rise to the Machadodorp tuffs and the Dullstroom lavas, both on the eastern side of the Transvaal only. These basic eruptive episodes provide indication of a subcrustal magma-reservoir beneath the Transvaal. The period of comparative quiet was ended by vast eruption of pre-

[1] It should be noted that the Fish River and Zwartmodder beds are parts of the Nama System and are probably much later in age than the Pretoria Series (Editor).

dominantly acid lavas—the Rooiberg Felsites—over the territory between Belfast and the Crocodile River in the one direction, and Bethal and the northern edge of the Palala Plateau in the other. Their manner of effusion is unknown, but in places so thick was the sheet of molten matter poured out at the surface that, weighed down by the overlying portion, the basal part was forced to consolidate not as compact felsite but as a coarse-grained granophyre. Speculation prompts us to regard the felsitic matter as the upper, differentiated fraction of the body of basic magma that was about to invade, or was already in course of invading, the underlying Transvaal System.

On the cessation of these eruptions sedimentation was re-established and quartzites and red and purple shales, sandstones, and conglomerates were able to accumulate in a gentle hollow occupying the centre of the Transvaal. Significantly, the facies of this sedimentation is an anticipation of that which characterised the Waterberg beds laid down somewhat later, after the introduction and partial erosion of the Bushveld Lopolith.

The Bushveld Igneous Complex.—To such an extent did the internal forces increase after this period, that ultimately Southern Rhodesia was split almost from north to south by a gigantic fissure filled from below with basic magma, while not improbably large volumes of molten matter were poured out at the surface, of which subsequent erosion has left no traces. During its cooling the magma became differentiated into a variety of plutonic types of varying degrees of basicity, the whole forming the intrusion known as the Great Dyke.

The basic magma-fraction was introduced into the heart of the Transvaal more or less along the plane of contact between the Pretoria and Rooiberg Series to crystallise as an immense cake of *Norite*, not improbably as a true laccolith with flattish base and faintly convex top, while the strata beneath—chiefly the Pretoria Series—became injected with a host of rudely concordant sills of diabase, under the combined influence of which the invaded sediments became intensely metamorphosed and even transfused. During its slow cooling this body became differentiated into types ranging from ultra-basic to acid, at the same time acquiring a stratified character through the growth of layers of rock rich in olivine, pyroxenes, titaniferous magnetite, chromite, or plagioclase. The emplacement of this huge volume of matter could not have been the result of a single act, but must have been a long-continued and probably rhythmic process, during which time the magma experienced considerable changes in composition.

The rising of the lighter acid fraction led to instability of the cover and to crustal collapse, and such magma, bursting through the floor, enveloped and floated-up enormous blocks of the lighter rocks and

spread out widely to form the immense sheet of the Red Granite, generally just above the Norite, *thereby converting the laccolith into a lopolith with concave structure.* Various pneumatolytic mineral deposits were formed close to or within the roof, those carrying tin being the most important, while further hornfelsing was produced in the Pretoria beds below.

The extraordinary up-doming in the Vredefort-Parys area with its intense metamorphism has usually been regarded as the final expression of the Bushveld activity, but is possibly of a much later date (p. 200).

The Waterberg-Matsap Transgression.—Following, but perhaps also accompanying the cooling of the Lopolith, came an extensive planation covering the area, including the Complex, and stretching far into Rhodesia, Bechuanaland, and Griqualand West; upon this surface were then deposited the sediments of the Waterberg, Matsap, and Umkondo Systems.[1] The magnitude of the erosion-interval can be judged from the fact that, although the Waterberg rests in the Middelburg district, without obvious discordance, upon the Upper Division of the Rooiberg Series (here forming the roof of the Lopolith), its base outside that region transgresses across the tilted edges of the Complex and of the Transvaal System to repose in the north and west on the Old Granite, a similar unconformable relationship holding for the Umkondo beds in south-eastern Rhodesia. In the case of the Matsap beds the latter rest usually upon the Campbell Rand or Lower Griquatown Series, but in the Ezel Rand on the Ventersdorp rocks and to the west of the Langeberg on the still older Kheis System. The strong denudation suffered by the Complex is proved by the pebbles of Red granite, granophyre, diabase, felsite, tourmalinised quartzites, etc., in the conglomerates of the Waterberg.

The latter with its prominent conglomerates, feldspathic grits, and sandstones and shales of deep red, brown, or purple coloration is very like the Torridonian or the Old Red Sandstone of Scotland, and was evidently laid down in an interior basin under shallow-water conditions, as shown by the false-bedding in the arenaceous rocks and the ripple-markings on the flagstones. The coarse material so frequently present suggests occasional torrential conditions, while the climate may have been sub-arid. Well-rounded grains of quartz occur in many of the Matsap grits. As developed in the Zoutpansberg, the Waterberg formation is more like the Matsap, paler, more quartzitic, and less feldspathic or conglomeratic, while the facies of the Umkondo with its calcareous horizons points perhaps to deeper water conditions in the

[1] See, however, editorial comment on p. 212. The author was not aware of Truter's later differentiation as the Loskop System of part of what he here accepts as Waterberg in the Middelburg area.

north-east and north—within the Zambezi Valley. The Umkondo is perhaps the equivalent of the Upper Kundulungu of Katanga.

Post Matsap Movements.—Widest in distribution and most profound in effect was this crustal activity under which extensive fold-ranges were thrown up with strong overthrusting locally in accordance with the pattern shown in Fig. 32 (see p. 204). The outermost branch runs north-eastwards from Rehoboth to Lomagundi. Far to the south is the arc striking north from the Doornberg near Prieska and then curving eastwards along the northern edge of the Bushveld to Leydsdorp, with the Matsap beds thrust eastwards on the west and the Waterberg pushed northwards on the east. Inside stretch the lines of disturbance along the northern side of the Middelburg Basin. The centre is made by the Vredefort Dome with its peripheral folds and faults set concentric therewith, though northward thrusting is still evident.

The Post-Waterberg Eruptions.—Doubtless connected with those crustal stresses (though whether preceding or following the folding is not yet clear) was the recrudescence of magmatic activity that culminated in the bursting up of matter of *alkaline composition* at a number of points in and around the Bushveld Complex. Chief of these occurrences was the huge vent of the Pilansberg with its lava accumulations and remarkable plutonic network, its closing phase marked by the seaming of the greater part of the area by the Bushveld Dyke System of basic and intermediate rocks, many of the intrusions being of alkaline character. The evidence is very strong that the alkalic composition of the prevailing magma at this time was developed by reaction in depth between injected masses of normal basic matter and the Dolomite formation. The eruptions represent an expiring phase of volcanicity, the interior of South Africa remaining thereafter quiescent until the close of the Triassic.

The Cape Transgression.—The evidence that the Table Mountain Series is distinct and younger than the Matsap has been set forth earlier. Over the southern half of the Cape before the close of the Silurian a peneplain had been developed from Van Rhynsdorp to Natal with hilly ground still remaining in Zululand and with sundry outstanding ranges in the Transvaal and Griqualand West. This surface sloped southwards towards an east-west trough—the "*Cape Geosyncline*"—just beyond the limits of the present continent. As shown by the pebbles in the Table Mountain Sandstone and by the coarsening of all three members of the Cape System when traced towards the north, that northern area provided the bulk of the sediments building up the Cape rocks; and certain facts suggest that the Matsap System also contributed.

South Africa already formed part of that continent well known in

later times as " Gondwanaland," its union with the other land-masses in the Southern Hemisphere being constituted by " land bridges," unless, following the " Displacement Hypothesis " (Fig. 1), the several elements are to be regarded as having been geographically closer together in those times.

Following depression during the early Devonian unfossiliferous white quartzose sands were laid down in extensive deltas, thereby forming the Table Mountain Sandstone and comparable formations of Falkland Islands, Argentina, Uruguay, and Brazil. The climate was sub-temperate or even cold, as the glacial horizon in the south-west of the Cape would suggest.

Geosynclinal sinking brought about a marine (Devonian) incursion with deposition of shallow, cool-water sediments, indicated by the Bokkeveld Series of the Cape and its equivalent representatives in the Falkland Islands and South America, the fossils of which all display that faunal aspect of the Devonian known as " *austral.*" Some elevation thereafter is indicated by the presumably brackish-water Witteberg Series with its counterpart in the Falkland Islands.

The Carboniferous Geography.—So far as this can be reconstructed, the land just before the onset of the Carboniferous refrigeration, as manifested in the Dwyka Conglomerate, was constituted somewhat as follows.[1] Over the bulk of South-West Africa, the Cape, Free State, and Natal the land stood low, probably not very high above sea-level, the elevated ground being concentrated in (1) the Windhoek highlands, (2) the Griqualand West block, and (3) the Transvaal. These masses must have stood higher relatively to the territory immediately surrounding them than now, since they must have suffered reduction in their relative heights through glacial erosion ; possibly few ridges exceeded 3000 feet above sea-level. Undulating country extended northwards to Central Africa, as well as far to the west and east, thereby linking up with South America, Madagascar and India.

South of latitude 33° stretched the waters of the Cape Geosyncline —now only a shallow estuary—while the Carboniferous ocean appears to have sent an arm to the west of the Cape in a northerly direction, which at the close of the Dwyka glaciation inundated the area of the Fish River in South-West Africa and introduced the molluscan *Eurydesma* fauna.

The Dwyka Glaciation.—As the temperature fell, ice-caps formed over the several centres (Fig. 41) and attained their maxima in order from west to east, merging and presumably making an ice-front that discharged into the water to the south, perhaps after the manner of the Great Barrier Ice of the Antarctic.

[1] The details of the Dwyka Glaciation are fully discussed in *T.G.S.S.A.*, 1921, xxiv, 183, and *XV Intern. Geol. Congr.*, 1930, ii, 90.

Under some such conditions as those here pictured was the boulder-bed of the Dwyka formed, having everywhere the characters of a *ground-moraine*, except in the extreme south, where the ice-sheet was probably buoyed up, though succeeded in particular areas by glacial muds with boulders dropped into either salt or fresh water and sometimes by fluvio-glacial sands and gravels. The parallelism with the glaciation of the Pleistocene is perfect.

With the passing of frigid conditions the ice of the western centre dwindled and allowed the Carboniferous ocean to invade the region from the west, whereas the Transvaal and extra-Natal masses vanished later. A body of fairly deep water followed up the retreating front in a north-easterly direction, within which the Upper Dwyka Shales—mainly glacial silts—were deposited, while the hilly ground of the Transvaal with its uneven covering of morainic matter remained exposed to subsequent erosion for a lengthy period, since it was not buried beneath younger deposits (Ecca) until well in the Permian and in places not until the late Triassic (Stormberg).

This extensive glaciation affected not only the region enclosed between parallels 22° and 34° and meridians 17° and 32°, but Angola and eastern Congo, to just across the equator and was not confined to this continent, having also been developed in the Falkland Islands, Argentina, Uruguay, southern Brazil, Madagascar, India, Australia, and Tasmania, though whether these various sections of Gondwana-land were ever linked to one another by a continuous girdle of ice during the optimum of glaciation must remain a subject for speculation. Despite the intensity of the climatic changes at this period, crustal movements were of small magnitude in South Africa, consisting mainly of moderate upheaval or subsidence along broad zones of country, while volcanism remained dormant.

"Post-Glacial" Changes.—With the conversion of the "*Cape*" into the "*Karroo Geosyncline*" during the Permian, the land lying to the south and east furnished the bulk of the sediments, as shown by their coarser and thicker nature and by their current-bedding, while on the northern or "foreland" side the succession was much thinner and marked by occasional breaks or changes of facies.

Most of the Southern Region (see p. 281) with its geosynclinal deposits was lacustrine to start with, becoming a great flood-plain dotted with temporary lakelets and traversed by broad ill-defined flood channels, the climate varying between cool and humid and warm and semi-arid in different parts and at different times. At more than one stage coal seams could form, principally in the east and north-east.

Karroo Conditions.—While the extent of such "*continental*" Karroo beds is very great in South Africa, it is probably more than doubled when the Congo and East African regions are included; but

this becomes enormously increased when the contemporaneous deposits of the other sections of Gondwanaland are also considered. Over such vast territories physiographical and geological conditions must have varied tremendously from point to point, wherefore it becomes particularly difficult to form a rational picture of the manner in which the beds were laid down as a whole, marked as they are by a poverty of fossils and general absence of marine forms.

Despite the intensity of post-Karroo erosion, some of the main troughs of accumulation can be made out, along the axes of which the lower divisions of the System were generally restricted, for, as the hollows became filled up, the higher horizons were forced to overlap on to the older rocks forming the margins. This applies to the " Northern Region " particularly.

Phases of the Karroo.—The principal lithological differences between the " Northern " and the " Southern Region," as detailed for the Ecca in Chapter XI, are summarised in the following comparative table, which brings out the radically dissimilar conditions under which the two types must have accumulated :—

Northern Ecca or Coal Measures (and also the Molteno beds).	Southern Ecca (and the Beaufort beds).
Climate, cool and humid.	Climate, temperate to warm and semi-arid.
Coarse grits and arkoses with fresh feldspar, pebbles, and occasional conglomerates.	Medium to fine, feldspathic sandstones with feldspar more or less decomposed ; no pebbles.
Grey, yellow or white.	Yellowish, often blue or greenish.
Cross-bedded, often largely from one direction.	Frequent irregularities in bedding.
Individual beds traceable over long distances.	Individual beds with not too wide an extension.
Softer strata shaly, though often " sandy," but clearly differentiated from the sandstones and usually well laminated, frequently micaceous.	Softer strata, mainly of the " mudstone " type even when sandy, ill-differentiated, and poorly laminated.
" Worm-burrows " not uncommon.	" Worm-burrows " usually absent.
Dark blue, grey, or black.	Blue, green, yellow, lilac, purple, or red, often mottled.
Calcareous nodules or bands absent ; pyritic nodules common in the sandstones—often oxidised.	Calcareous and dolomitic bands and concretions common both in the mudstones and sandstones.

Seams of coal, torbanite and fireclay.	No coals or fireclays.
Silicified wood usually absent from Ecca but present in Molteno; plant stems common in sandstones and leaves in the shales.	Silicified wood common; plant impressions not abundant.
No vertebrate remains.	Reptiles, amphibians, and fishes common.
Mollusca very rare.	Mollusca not infrequent.
Deltaic and fluviatile in origin.	Lacustrine, " basin," and æolian in origin.

Physiography of the Ecca.—Guided by the above, the history during this period can be interpreted somewhat as follows :—In the south of the Cape, after the lowest beds of the " Green Ecca " (mainly lacustrine shales) had been laid down, the water area was encroached upon from the south by sediments of less fine a grain, and from thence onwards right through the Beaufort this appears to have been a tract of varying width alternately just submerged or just exposed to the air, whereon sandy muds, alternating with fine wind-borne sands (probably largely rearranged by water) were deposited. Frequently the silts were dried out and oxidised, while the excess of calcareous matter collected to form nodules.

Following the lower shales in the east and north-east, gravels, sands, and muds derived from the higher ground in this quarter commenced to be deposited in the valleys bordering the " lake," and by gradual extension southwards and westwards produced a series of flats merging with the " playa " or " basin " of the Cape. Instead of the succession of ill-bedded material ranging from rather bright-coloured muds to fine sands, one finds throughout Natal, the northern Free State, and the Transvaal a well-marked alternation of stratified shaly beds—often carbonaceous—and coarse grits and pebbly sandstones. The variable false-bedding in Vryheid points rather to a north-easterly and the more constant planes in central Natal to an easterly source for these sheets of coarse sandstones.

Vegetation, growing out into swamps bordering the high ground, gave rise to beds of coal and, as the shallow valleys became silted up, the environment favourable for coal-formation was transferred farther back into the higher ground, so that the succeeding seams overlapped those previously formed, a relationship well seen for example in the Witbank Coalfield.

Over much of the Transvaal, throughout Rhodesia and along the Zambezi these Middle Ecca Coal Measures were laid down directly on the floors of the depressions of an ancient land surface. In the extreme

north torrential conglomerates mark their base and, speaking generally, the precise conditions for coal-formation were not properly attained until a somewhat later date.

In Gordonia and South-West Africa the estuarine Dwyka shales pass up into the " Red Ecca," a totally different facies, characterised by red and green shales and mudstones and peculiar brown calcareous sandstones, followed by some thick bodies of reddish or yellow sandstones, the mode of accumulation of which is not properly understood. No seams of coal worth considering have as yet been discovered in these strata.

The Late Ecca Submergence.—Through sinking in the north-east and north lacustrine conditions were established over much of this northern region—even in Southern Rhodesia and Nyasaland—and the Upper Ecca shales were now laid down. Their deep-water origin is indicated by their fineness in grain, even stratification, uniform dark blue or blackish colour, by phosphatic nodules carrying fish remains (in Natal) and by the absence of plants and reptiles. During the slow drowning of the old land-surface lying to the north, conditions favourable to the forming of coal would have been progressively formed and destroyed, wherefore the alternations of shale and coal towards the base of this Shale group in the region extending from the Waterberg northwards, so that in Rhodesia and Nyasaland these coals constitute the main workable seams.

The constant association of the coals within shales, their interlamination with and passage into shaly layers, their microscopic structure, the absence of fireclays, and the fragmentary nature of the plant remains all point to these northern seams being " *drift coals*," whereas those of the Middle Ecca were mostly formed *in situ*. It should also be observed that during the early Beaufort the particular conditions determining coal-formation were reproduced in Natal and Zululand.

The Beaufort Series.—At the close of the Ecca the peculiar geographic conditions that were prevailing in the Karroo region became extended farther towards the north-east.

In the Karroo itself many features collectively point to there having been periods of dessication followed by times of flooding during the deposition of the Beaufort—for instance, the many local unconformities and wash-outs, the presence of bands of clay-pellet and sometimes of limestone-pellet conglomerate with fragments of bone at the base of the sandstone bands, the occurrence of red, purple, and green poorly-stratified mudstones, the frequent calcareous concretions, the scarcity of plants. The fact that reptilian remains are fairly plentiful in the west and south intimates that the surface there must generally have

been dry enough for the vertebrates to move about freely. In numerous cases the skeletons are found still articulated, while some of the Pareiasaurians even died in an upright position, their bodies having been covered up by dust or drifted sand. The development of temporary lakelets or " vleis " during this period is disclosed by the occasional finds of shaly layers containing fish remains, freshwater lamellibranchs or crustacea. During the Middle and Upper Beaufort the conditions changed to this extent that the finer silts were of a deep red, purple, or bluish-green colour, often variegated, with calcareous concretions ; reptiles, amphibians, and fishes are still represented.

The Beaufort Series of the Union and its subdivisions thin in a northerly direction and are not represented in South-West Africa or north of Amersfoort in the south-eastern Transvaal, though extending through northern Zululand. It reappears to the north of Bulawayo, where in the trough of the Zambezi from Wankie north-eastwards are to be found the comparable Madumabisa Shales with similar fossils. The Series is also present in Nyasaland, having in places a distinctly calcareous facies.

The Stormberg Overlap.—Earth movements were initiated over the southern end of the continent towards the close of the Permian developing into the " Zwartberg Foldings " with roughly east-west axes and involving Karroo strata up to the Lower Beaufort (Upper Permian) Beds. The middle of the Triassic appears to mark the culmination of this intense compressive movement and the coarse waste shed from the crumpling and rising mass in the south and south-east was carried northwards and spread out in a great " delta fan " over the Stormberg and Basutoland region almost as far as the Transvaal border ; so were formed the Molteno beds.

In the south the Lower Karroo strata must have been denuded off the crests of the rising folds, for boulders of Witteberg quartzites are characteristic of the Molteno grits, becoming more numerous and also larger as the outcrops of the latter are traced towards the south. Indeed, just to the south of the Zuurberg (Suurberg) Range the intensity of the erosion was such that towards the close of the Triassic the Bokkeveld slates were being laid bare ; probably in the region still farther to the south the pre-Cape granites were exposed and so furnished the feldspathic matter for the Molteno and Red Beds sandstones.

The conditions at the commencement of the Stormberg epoch appear to have been almost identical with those determining the Ecca Coal Measures (see previous Table), favouring the growth of vegetation and the forming of coal seams, but, on the other hand, such as to drive away animal life from the region ; the rainfall must have been high and the climate cool. A rather similar order of things prevailed in the Zambezi Valley, where the Beaufort beds in the still-deepening syncline

were being covered by the coarse, fluviatile deposits known as the Escarpment Grits, presumably equivalent to the Molteno group.

So far as can be judged, only in the south and in the extreme north-west and north-east were sediments being accumulated during the Molteno stage (Upper or Middle Triassic) ; elsewhere the surface of the continent—including that made by the previously formed Beaufort or older beds—was being actively denuded. Furthermore, such a state of affairs was not confined to this country, since in certain other portions of Gondwanaland at about the middle of the Triassic a break also occurs, proof of a very widespread erosion-cycle.

Arising out of subsidence and other causes the subsequently formed divisions of the Stormberg Series proceeded to transgress across the much older formations along this erosional feature, for example about Mariental in the north-west, south of the Zuurberg in the Cape, in the Transvaal and southern parts of Rhodesia, and probably also in Zululand. The temperate climate of the south with its ample rainfall gave way to warmer and more arid conditions that extended themselves over the entire country—largely a reversion to those prevailing during the Upper Beaufort—the earth movements died down, and fine-grained sediments of a red and purple hue were deposited far and wide. The restoration of former conditions brought about the return of animal life to the region, and dinosaurs and animal forms ancestral to the crocodiles and birds roamed the continent.

The Late Triassic Desiccation.—The history of the closing stages of the Karroo Epoch makes a fascinating study. The red and purple muds of the Red Beds of the Southern Region and the similarly tinted "marls" of the Lebombo, Springbok Flats, Limpopo Valley, and probably of the Kaokoveld, and even some of the still-projecting higher ground became buried beneath a widespread covering of pale to reddish sands of extraordinarily even grain ; through this mantle the higher parts of the country protruded. This accumulation is the formation respectively known in different areas as the Cave, Bushveld, or Forest Sandstone and which, generally a few hundreds of feet thick, attains to a maximum value in the south of 1000 feet.

The aridity that had already showed itself during the period of the Red Beds had now become intense, for the sandstones in the north bear all the characters of *desert origin*, as betrayed by the marked roundness and worn nature of the grains, the peculiar false-bedding but lack of stratification, and the local secondary silicification among other features. A progressive change is traceable into the Cave Sandstone of the south that, in its great thickness, uniformity, lack of bedding, angularity of grain and the presence of calcareous nodules in the base, recalls the Pleistocene loess of the Northern Hemisphere. One can consequently picture an immense arid territory, comparable

in some respects with the Kalahari, within which isolated ridges of the older rocks were in process of becoming buried beneath wind-borne dust. Such a comparison is the more appropriate when it is remembered that the red æolian sands of the Kalahari region are underlain in the south-east by pink marls, by sands, etc., rather like the Bushveld marls and those of the Red Beds : facts that point to a repetition of such conditions in the Tertiary. It should be observed, too, that during this particular epoch desert conditions developed in south-eastern Brazil and also in parts of Europe ; indeed, the aridity at the close of the Triassic seems to have been almost universal.

We can conclude that at the end of the Triassic South Africa was a vast waste covered by a mantle of fine cream or red sand, its surface crossed at rare intervals by gentle hollows, certain of which have been preserved for our inspection beneath the succeeding lavas. Trunks of silicified wood show that these flats were not treeless, while the life of the time consisted chiefly of dinosaurs and other allied vertebrates.

The Mesozoic Eruptions.—A termination to this state of affairs was brought about by the eruption of vast floods of basaltic lavas and, whether we are correct or not in regarding the various known occurrences in South Africa as formerly joined together—the area being so vast—there can be no doubt as to the hugeness of the several tracts over which the erupted matter was locally spread. The region with Basutoland as its centre is 300 miles long, with the strip beneath the Zuurberg (Suurberg) Range in the Cape far to the south ; the arc of the Lebombo extends through more than eight degrees of latitude ; there are the detached areas of the Springbok Flats, Zoutpansberg, Kalahari, Tete, the wide region between Bulawayo and the Victoria Falls, the lavas of Mariental and far to the north-west the outpourings of the Kaokoveld. Moreover, in South America we find the contemporaneous eruptives of southern Brazil, Uruguay, and Paraguay that cover a truly enormous region, as well as some in Argentina.

So far as is known *volcanoes* were developed in and played an important rôle only in the Basutoland section, in which the total number of pipes can be estimated at about several hundred, though the majority of them were merely perforations of the earth's crust from which no lavas issued, nor were true cones built up ; they were purely " gaseous " in fact. Presumably the effective eruptions were of the *fissure type*, the magma repeatedly welling out of cracks in the crust communicating with channels fed from a subterranean reservoir ; the feeders are doubtless now indicated by the narrow dykes constituting part of the dolerite network of the Karroo.

The relationship of the intrusive dolerites to the lavas is an intimate one, but the pile of erupted material became apparently so great at length that the magma was prevented from reaching the

surface and consequently burst its way through the strata beneath in the form of a network, largely through tension-rifts.

The individual flows must have followed one another freely and rapidly, so that the upper surface of each was never subjected to prolonged exposure, while the fact that many can be traced for many miles implies a high fluidity. Ash-beds are practically restricted to the area south of lat. 30°, that is to say to a region characterised by eruptions of the " central type." Intercalated sandstones are found not only in that region, but in Rhodesia, Nyasaland, South-West Africa, and perhaps the Transvaal, though always sparingly and in the lowest few hundred feet of the group only. Some of these bands suggest layers of wind-borne dust.

Noteworthy are the uniform petrological characters of the lavas throughout the wide territory involved; they are *basalts* with little or no olivine, or *basaltic-andesites*, almost habitually showing layers with the peculiar branching vesicles known as " pipe-amygdaloid " at their base. Within a wide region—including the Tuli area, the country north of the Zoutpansberg, and the northern end of the Lebombo—the basal volcanics are represented by *limburgites* and *alkaline lavas* resting on a slightly eroded surface of Bushveld Sandstone, and are cut by narrow dykes of dolerite or limburgite. In the Lebombo the basalts are overlain by *rhyolites* to a great depth, succeeded in turn by basic types. Such acid effusives reappear in the Kaokoveld and on the Lower Zambezi. From 1000 to 4000 feet of volcanics have been measured in different places, but in the Lebombo, where they dip eastwards beneath the Cretaceous beds, their thickness must be enormous. *Granite-granophyre* intrusions of considerable extent mark the Lebombo-Sabi and Erongo-Kaokoveld zones.

The beginning of the Jurassic found South Africa a vast waste of semi-arid lava plains in process of elevation and doubtless of active dissection along their margins, but the evidence available is too meagre to decide whether a condition comparable to that of the " End-Jurassic Peneplain " [1] had by then been attained.

The Mesozoic Foldings.—The Stormberg volcanic and intrusive episode has been connected with the compression and upheaval—as manifested in the " Cape foldings "—of the long-lived " Cape Geosyncline," an activity that was, however, not confined to this country, but reached to South America on the one side and to Tasmania and Antarctica on the other. This leads to the observation that the pear-shaped outline of the southern end of the African continent appears to have been developed out of the mass of Gondwanaland through flexing and faulting along three successively-formed, intersecting arcs, within each of which a renewal of crustal movement took place at some

[1] F. Dixey, *T.G.S.S.A.*, 1939, xli, 113.

later date; the outer limits of each belt lie beneath the waters of the ocean (see Fig. 3).

(1) On the Atlantic side the "*Cedarberg Foldings*" sweep southwards in an arc from Van Rhynsdorp through Clanwilliam to near Caledon. The three components of the Cape System are thrown into anticlines and synclines, gentle in the north, but more pronounced towards the south, where they link up with and become modified by the seemingly later Zwartberg (Swartberg) foldings. From the fact that the Witteberg beds on the Tanqua River show signs of flexing prior to the deposition of the Dwyka tillite, it would follow that the movement was initiated as far back as the Middle Carboniferous, but must have continued into or else been renewed during the Permian and later, since both the Dwyka and Ecca beds have been involved. The Cedarberg foldings merely follow the previously established zone of compression, wherein the much older Nama beds had suffered crumpling in pre-Cape times. The trend lines are splendidly displayed by the various mountain ranges, chief of which are the lofty Cedarbergen.

(2) The "*Zwartberg Foldings*" make a series of roughly concentric arcs concave to the south, though with a general west-east direction, meeting the Cedarberg set almost at right angles (this giving rise to the structure known as a "syntaxis"), and covering the entire south of the Cape to a width of fully a hundred miles. The formations up to the Lower Beaufort are involved in a succession of anticlines and synclines, for the most part asymmetrical and even inverted in certain sections, as though under pressure exerted from the south. While the arches may run regularly for miles, the folds frequently pitch to the east or west, so that the outcrops of formations zigzag or are arranged *en échelon*. The intensity is greatest in the centre and south, *e.g.* Zwartebergen (Swartebergen) and Zitzikamma (Sitsikamma), where the beds are highly crumpled, the foldings becoming less acute within the borders of the Karroo, and fading out into gentle undulations before the higher ground in the north made by the flat-lying Beaufort beds is reached. In the Western Province, on the other hand, arches have been pushed up trending north-east or north-west owing to the compounding of the Zwartberg and the Cedarberg foldings.[1]

Before the close of the Triassic the bulk of the Cape foldings and much of their subsequent erosion had taken place, for to the south of the Zuurberg (Suurberg) the presumed Stormberg volcanics repose in a syncline upon the edges of the highly compressed Cape and Dwyka beds. A renewal of movement occurred, however, during the Cretaceous, as will be detailed later.

[1] See A. Born, "Zur Analyse des Cap-Falten Systems," *Zeit. D. Geol. Ges.*, 1930, lxxxii, 193; J. de Villiers, "A Review of the Cape Orogeny," *Ann. Univ. Stellenbosch*, 1944, xxii, Sect. A, 183.

(3) " *The Natal Foldings* " are revealed almost solely in the lengthy monoclinal flexure of the Lebombo by which the entire Karroo System, including the basaltic and rhyolitic lavas, was given an easterly tilt at angles of from 5° to 45°, more usually at about 12°. The Monocline can be followed southwards to the mouth of the Umtata River in Pondoland, shifted at Empangeni, Embotyi, and a few other places by diagonal fractures. The preservation of synclinal structures in the Karroo beds along the coast between Durban and Mount Edgecombe and also at Port Shepstone suggests that this monocline may be the beginning of a series of synclines and anticlines belonging to an arc of folding all but concealed beneath the ocean, one that when continued to the south-west would meet the prolongation of the Cape foldings in another " syntaxis " corresponding to that of the Western Province.

The enormously thick volcanic sequence of the Lebombo was erupted from a remarkable swarm of fissures trending north-south and the monoclinal structure was produced during the middle of the eruptive period, that is to say about the Liassic, and was apparently attended and followed by faulting.

From the evidence on the Umgazana River near Port St Johns this flexing and fracturing of the crust continued into the Lower but had ceased before the Upper Cretaceous.

Lower Cretaceous Sedimentation.—By the end of the Jurassic mountain-building in the south had apparently ended and the strike-valleys, no longer under active erosion, were becoming choked with waste that produced the brackish-water facies of the Uitenhage Series —red conglomerates, soft sandstones, and red and white clays. With subsidence the sea entered the main troughs from the south-east converting them into estuaries and gulfs. These intermontane deposits were probably accumulated under a semi-arid climate, as suggested by their frequent red coloration, the torrential aspect of the conglomerates, the poor stratification of the clays, the presence of gypsum in them, and of salts of sodium and magnesium in the characteristically saline ground-waters. Nearer the coast they pass up into drab estuarine strata and finally into grey or bluish marine beds with a shallow-water fauna of Neocomian age.

In the south of the Cape the record ceases at this stage, but in the coastal region extending northwards from Zululand the ocean lapped the base of the Lebombo from the Neocomian to the Albian or even later, coarse conglomerates being well developed to the north of Komati Poort, particularly upon the Limpopo. More to the north-east such strata furnish strong evidence of aridity.

The faunal resemblances of the South African Lower Cretaceous are with those of Moçambique, Madagascar, and India, and do *not* support the view of any direct connection with the central or northern

Atlantic *via* the Cape, since the equivalent formations in Angola possess fossils of the Mediterranean facies.

Mid-Cretaceous Fracturing.—(*a*) While the scale and pattern of the faulting around the southern end of Africa is growing clearer, the evidence is tending to show that, while much of it must date to the Mid-Cretaceous, some in the north-east must be as old as late Jurassic. *A progressive marginal fracturing from north-east to south-west* seems indeed suggested (Fig. 3). In Zululand, where the Senonian lies unaffected across the great Empangeni Fault, the time available for the planing-down of the fault-scarp would seem too brief had the break occurred during the Mid-Cretaceous.

(*b*) On the contrary, the Lower Cretaceous at Embotyi in Pondoland was strongly faulted, whereas the Upper Cretaceous not far away is unaffected. Right along this coast from Zululand to the Transkei successive strips have been bent down on their seaward side and severed from their neighbours by north to north-east fractures that fade out inland.

(*c*) In the south of the Cape the fracture lines, trending east-west, follow the Cape arcs, but may cut obliquely across those earlier folds—as to the south of the Suurberg—curving in the westerly direction towards the south-west and north-west in conformity with the older diagonal folding in those quarters, while in Clanwilliam and Van Rhynsdorp they run almost parallel to the Cedarbergen. Throughout this wide region the downthrow is towards the ocean as a rule, as though due to the removal of lateral support on that side—indicative of *crustal tension.*

Almost everywhere the Uitenhage beds dip *towards* the fault-line, sometimes at considerable angles. In the Swellendam-Heidelberg basin and in that of Oudtshoorn the dips are almost universally northwards at from 10° to 25°, and near Uniondale Road up to angles of 45°, but between Sapkamma and Cockscomb Stations on the northern side of the Uitenhage syncline southerly inclinations of up to 50° are to be found. Cross-warping, or else varying displacements along the strike, have caused the Cretaceous beds to occupy a series of "*fault-basins*" bounded on their northern side by a fault or fault-scarp; those in Baviaans Kloof form an excellent illustration.

Some of the fractures are of huge vertical displacement and Rastall's and Söhnge's studies of the Worcester Fault with a maximum throw of about *two miles* indicate that the dislocative movement was a gradual one: that, as the ground rose on the northern side of the fracture, the fault-scarp was actually being denuded and the waste therefrom spread out within the depression forming in the south. It is a normal or tension fault dipping at 70° to 90° to the south. The same peculiarities mark the Ladismith-Baviaans Kloof fault (p. 385).

(*d*) The main trough-faulting in the Kaokoveld is parallel to the coast with final drop to sea-level. Between Namaqualand and Keetmanshoop there has been severe post-Dwyka faulting with coastward downthrows and north-north-easterly strike, as in the Karas Mountains.

(*e*) Finally come the two important zones trending north-east :— (i) along the northern Waterberg and Soutpansberg, the Sabi and Buzi valleys and the Urema trough, and (ii) the Gobabis-Lake Ngami-Deka-Wankie and Sengwe belt, continued by the mid-Zambezi trough and by the Machinga fault-scarp of the Luano Valley beyond, much of which may, however, be of Tertiary age.

All this extensive fracturing, spread out over a lengthy period, is thought to mark the breaking up of Gondwanaland, either through drowning of large portions thereof or, according to the " Displacement Hypothesis," to the drifting away of sections with the forming of the Moçambique Channel. In the Lower Zambezi Valley alkaline lavas were erupted at about this time.

The Cretaceous Ocean.—Throughout this long period of crustal adjustments the limits of the ocean, curiously, do not appear to have shifted to any large extent, so that during the late Cretaceous its waters are once again found impinging on the south-eastern side of the Union, as testified to by the Senonian of Pondoland and Natal, but just as of old, spreading out farther to the west within Portuguese Territory, with the nearly north-south-trending Lebombo Range forming a long, almost straight coastal chain and reaching ultimately to the south-eastern border of Rhodesia. Progressive deepening of the ocean in the Beira region is shown by the continuous upward passage of the Danian stage into the foraminiferal limestones of the Eocene. Such depression of the continent finally brought about the junction of the Cretaceous " Indian " and " South Atlantic " oceans during the Senonian, and thereby completed the separation of Africa from South America and Antarctica.

The Kimberlite Eruptions.—The host of volcanic pipes—and the " fissures "—dotted about over South Africa, usually in groups, that are filled with those uncommon rocks, kimberlite, melilite basalt, or siliceous breccia, mark a recrudescence of magmatic activity of an astonishingly widespread character. The fact that kimberlite and melilite basalt pierce the previously tilted Lower Cretaceous beds in the Heidelberg district of the Cape proves them to be *later* than Middle Cretaceous.

In the United States the diamond-bearing peridotite-breccia of Pike County, Arkansas, has been found to cut Lower Cretaceous, but to be older than Upper Cretaceous strata.

In the absence of more precise evidence, all that can be said is that matter was erupted from a multitude of perforations and fissures tapping an ultrabasic stratum within the crust at some date towards or just after the close of the Cretaceous, at a time when folding and faulting had practically ceased and up and down movements of the crust were alone in progress. It is a matter of observation that the materials erupted during intervals of " plateau uplift " are frequently alkalic in their composition, which is of significance, since the kimberlite suite of rocks, although of ultrabasic composition, nevertheless exhibits alkalic affinities, best displayed by the associated nepheline basalts. It can be suggested that this unique phase of volcanicity was perhaps related to the upheaval of the interior of the continent, coupled with the deepening of the contiguous oceanic basins. The Cretaceo-Tertiary was certainly a period marked out by alkaline and often highly basic lavas in this continent, as is shown by the Cretaceous outpourings of the Lower Zambezi and by the Tertiary ones of Moçambique Territory and of South-West Africa.

Tertiary and Quaternary Planation and Warping.—From the Jurassic onwards South and Central Africa underwent various cycles of prolonged planation, the most widespread one being that of the late Tertiary.[1] Each was followed by uplift, by some depression and possibly some warping, and these by renewed upheaval. Within a few hundred miles of the coast a " hinge-line " was initiated, where the repeated upthrusts seem to have attained their maxima, exemplified by erosion-surfaces at 7000 feet in the east of Southern Rhodesia, 6500 feet in the Naukluft Mountains of South-West Africa, 4500 feet in the Kamiesberg and 4000 feet in the Klein Zwartberg and along the Langebergen, the less elevated interior becoming converted into the Kalahari, girt by blocks of higher ground—the " Upland Regions " of Fig. 2.

(a) *Interior Region.*—Into this shallow central depression various drainages were diverted and, aided by an increase of rainfall, clays, sands, and even gravels were laid down upon it, mainly in the south and west—the Kalahari beds—the age of which remains in doubt. In addition to this progressive basining, lines of warping developed across South Africa trending north-east to south-west, *e.g.* Rhodesia-Kalahari axis, Khomas axis, etc. (Fig. 3), accompanied by minor faulting, which through the medium of the Urema " sunklands " can be connected [2] with the series of gigantic crustal dislocations traversing the eastern section of Africa, known as the " Great Rift System,"

[1] F. Dixey, *T.G.S.S.A.*, 1939, xli, 113.

[2] A. L. du Toit, *S.A. Geogr. Jnl.*, 1933, xvi, 3; H. B. Maufe, *ibid.*, 1935, xviii, 3.

along which fracturing operated down to a very recent date, accompanied by periodic effusions of lavas.

During the late Tertiary desiccation set in over a vast region in more than one phase, that culminated in the spreading during the early Pleistocene of the Kalahari Sand, blotting out drainages, and that would suggest a former southward displacement of the climatic girdles.

(b) *Coastal Lowlands.*—Although far closer dating is possible here, all recent evidence only serves to emphasize the complexity of the interaction between the isostatically rising continent and the strongly oscillating ocean during the period covered by the Great Ice Age. Even for the closing Pliocene surprisingly large amplitudes in such movement are indicated in the south—from the 700-800-feet coastal peneplane down to the shallower part at least of the Agulhas Bank at say minus 300 feet, with as great an uplift, coupled with warping and some faulting, in the north-east at Inyaminga.

These oscillations of sea-level throughout the Pleistocene stand revealed by raised beaches, old sea-caves, and occasionally shells at various heights (p. 464). The corresponding climatic variations can, however, only be deduced from the strata of the interior as dated by artefacts or faunas.

The instability of this extremity of Africa is incidentally brought out by the occasional *earthquakes* that centre around the Waterberg, Zoutpansberg, Koffiefontein, and Vryheid, while a strong quake occurred at the end of 1932 off Cape St Lucia.[1] Shocks are common at Windhoek, especially in a north-south zone to the west of the town. West of the Naukluft Mountains a recent north-south fault is traceable for miles, displacing tufas along the dry river banks with coastward downthrow (Martin).

Evolution of the River Systems.—The primitive interior drainages were appreciably influenced by the earlier " Rift Movements," hence the north-east to south-west trend of the Upper Orange and its tributaries, the Middle Limpopo, Middle Zambezi, etc. The conspicuous sub-parallel rivers flowing south-east and north-west from the Rhodesia-Kalahari axis are assumed to be " consequent streams " resulting from upheaval along that line and incidentally antedate the Kalahari Sand. The view that the Okavango originally drained into the Limpopo, though physiographically possible, is not supported by the fossil shells (Rogers) and the Okavango must formerly have joined the Zambezi.

Remarkable is the way in which the rivers in the south of the Cape take their rise beneath and to the south of the main watershed, yet right behind the barrier ranges shutting in the Karroo, which they

[1] L. J. Krige and F. A. Venter, *T.G.S.S.A.*, 1934, xxxvi, 101.

traverse in huge ravines on their way to the southern ocean. There are grounds for believing that, after the longitudinal (east-west) valleys to the south of the Zwarteberg, Zuurberg, etc., had become deeply filled with Cretaceous deposits, cross-warpings diverted these primitive east-west drainages through synclinal depressions in the parting ranges, and with the new north-south courses once established, the rivers—greatly aided in their action by elevation of the continent and the acquisition of steeper gradients—were able to deepen their channels within the ranges of hard Cape rocks.[1] This drainage is instructive, because of the " subsequent " tributaries characteristically developed along belts of weaker strata, frequently synclinal in their structure, whereas the incised " antecedent " north-south rivers pass transversely through the hard anticlinal barrier-ranges ; instances of " river piracy " and " stream interference " are numerous, as, for example, about Uniondale. Behind the barrier the strata have been eroded up to the face of the Great Escarpment, the retreat of which is still in progress.[2]

An analogous case of "superimposed drainage " is presented by the Lebombo Range, gashed through by no less than eleven rivers.

Onward from the eastern end of the Cape fold-belt the streams originated upon and therefore meandered over the Tertiary peneplane, and their windings, initiated thus far back, are perpetuated in their present deeply eroded and winding channels, as for instance the Great Fish, Great Klei, or Bashee rivers.

All round the southern end of the continent the recent and quite considerable uplift in the Tertiary Epoch has caused each of the larger rivers to develop cataracts or rapids in some portion of its course ; this has been an effective hindrance to navigation and is in marked contrast to the evenly graded channels of the Niger and Nile, or the large waterways of South America.

The Human Period.—Surprisingly little is known about the animal life of the Tertiary. The forms described from the Miocene of the Lüderitz littoral are chiefly rodents indicative of " steppe " conditions in that part of the country.

The Pleistocene faunas are wider spread and represented by species, largely extinct, of mammoths, elephants, giraffes, horses, zebras, pigs, and various antelopes and carnivores. The boundary between Pliocene and Pleistocene is of necessity vague, though elsewhere widely defined by the incoming of *Bos*, *Elephas*, and *Equus*. Tentatively this seems to hold in South Africa, but may require modification.

The discovery of the ape-form *Australopithecus* has been followed by that of the astonishing Man-Apes, *Plesianthropus* and *Paranthropus*, that display extraordinarily human characters, and that have aroused

[1] A. W. Rogers, *T.S.A.P.S.*, 1903, xiv, 375.
[2] A. W. Rogers, *P.G.S.S.A.*, 1920, xxiii, p. xix.

world-wide scientific interest. The intensive excavation in progress inspires us with the hope of being able to recover well-preserved remains of those elusive primitive beings, who fabricated and used early palæolithic tools. With so vast and fascinating a field to hand for such investigation a far more comprehensive and illuminating picture should ere long be possible of Man's Evolution and Environment during the Quaternary Era in Southern Africa—our ultimate goal in Historical Geology.

EXPLANATION OF NUMBERS IN TABLE OF ROCK ANALYSES

1. Limburgitic Greenstone, Rhodesian Schists, Bembesi. Golding, *S.R.G.S.*, Bull. 29, 1936, No. 104.
2. Greenstone-Schist, Fred Mine, Filabusi (mean of 4). Ferguson, *S.R.G.S.*, Bull. 27, 1934, 32.
3. Epidiorite, Rhodesian Schists, Filabusi. Golding, *loc. cit.*, No. 94.
4. Serpentine, Malelane, Barberton. Hall, *Union S.A.G.S.*, Mem. 9, 1918, 302.
5. Talc-carbonate rock, Chrome Mine, Selukwe. Golding, *loc. cit.*, No. 134.
6. " Old Granite " Batholiths of S. Rhodesia (mean of 24). Golding, *loc. cit.*, Nos. 3, 7-27, 29, 30.
7. Old Granite, Orange Grove, Johannesburg. Wade, *Geol. Mag.*, 1909, 551.
8. Old Granite, Parys (mean of 3). Willemse, *T.G.S.S.A.*, 1937, xl, 90.
9. Charnockite, Port Edward, Natal. Gevers and Dunne, *T.G.S.S.A.*, xlv, 1943, 201.
10. Felsite, pre-Cambrian, Darwin, S. Rhodesia. Golding, *loc. cit.*, No. 41.
11. Marundite, Leydsdorp. Hall, *T.G.S.S.A.*, 1922, xxv, 52.
12. Mica diorite, Namaqualand. Rogers, *P.G.S.S.A.*, 1916, xix, 21.
13. Ventersdorp Amygdaloid, Johannesburg. Horwood, *T.G.S.S.A.*, 1910, xiii, 39.
14. Ventersdorp Amygdaloid, Heidelberg. Rogers, *Union S.A., Geol. Expln. Map of Heidelberg*, 1922, 46.
15. Felsite, Elands River, Pretoria. Lombaard, *T.G.S.S.A.*, 1932, xxxv, 151.
16. Younger (or " Nama ") Granite, Kuboos, Namaqualand (mean of 6). Van Biljon, *T.G.S.S.A.*, 1940, xlii, 178.
17. Younger or Cape Granite, Cable Station, Cape Town. Mathias, *T.G.S.S.A.*, 1941, xliii, 198.
18. Bushveld Diabase, Lydenburg Station. Lombaard, *T.G.S.S.A.*, xxxvii, 1935, Tab. 11.
19. Anorthosite, Pilansberg area. Wagner, *Union S.A.G.S.*, Mem. 21, 1924, 64.
20. Feldspathic Norite, Pilansberg area. Wagner, *loc. cit.*, 61.
21. Norite, Bon Accord. Hall and du Toit, *T.G.S.S.A.*, 1923, xxvi, 85.
22. Diallage Norite, Pilansberg area. Wagner, *loc. cit.*, 72.

23. Bronzitite, Pilansberg area. Wagner, *loc. cit.*, 44.
24. Hartzburgite, Pilansberg area. Wagner, *loc. cit.*, 49.
25. Hortonolite dunite, Rustenberg. De Bruyn, *Ann. Univ. Stellenb.*, 1944, xxii, Sect. A, Tab. IV A.
26. Norite, Great Dyke, Hartley district. Golding, *loc. cit.*, No. 73.
27. Websterite, Great Dyke, Umvukwe. Golding, *loc. cit.*, No. 68.
28. Granophyre, near Premier Mine. Horwood, *T.G.S.S.A.*, 1910, xiii, 51.
29. Granophyre, Stavoren. Wagner, *Union S.A.G.S.*, Mem. 16, 1921, 32.
30. Red Granite, Roodepoortje. Horwood, *loc. cit.*, 47.
31. Red Granite, Saltpan. Wagner, *Union S.A.G.S.*, Mem. 20, 1922, 34.
32. Bushveld Granite (Bobbejaankop), Zaaiplaats. Liebenberg, *T.G.S.S.A.*, 1945, xlvii, Tab. 2.
33. Arfedsonite granite, Vredefort. Molengraaff and Hall, *Konin. Akad. v. Weten. Amsterdam, Proc.*, 1924, xxvii, 472.
34. Red Syenite, Leeuwfontein. Shand, *T.G.S.S.A.*, 1921, xxiv, 241.
35. Foyaite, Leeuwfontein. Brouwer, *Oorsprong en Sam. d. Trans. Nephalien Syenieten*, 91.
36. Foyaite, Pilansberg. Shand, *T.G.S.S.A.*, 1928, xxxi, 130.
37. Phonolite, Hamans Kraal. Shand, *T.G.S.S.A.*, 1923, xxv, 92.
38. Tinguaite-porphyry, Paardefontein. Brouwer, *loc. cit.*
39. Tonalite, East Rand. Horwood, *T.G.S.S.A.*, 1910, xiii, 51.
40. Basalt, Basutoland. Stockley, *Rep. Geol. Basutoland*, 1947, 54.
41. Basalt, Goba, Port. E. Africa. Young, *T.G.S.S.A.*, 1921, xxiii, 111.
42. Basalt, Zuurberg, Cape. Haughton and Rogers, *T.R.S.S.A.*, 1924, xi, 245.
43. Basalt, Victoria Falls (mean of 5). Golding, *loc. cit.*, Nos. 62-6.
44. Limburgite, Letaba River, Transvaal. Herdsman (unpublished).
45. Nepheline basalt, Limpopo River, Zoutpansberg. Rogers, *T.G.S.S.A.*, 1925, xxviii, 50.
46. Rhyolite, Lebombo. McL. Henderson, *T.G.S.S.A.*, 1909, xii, 25.
47. Orthoclase porphyry, Kaokoveld (mean of 4). Reuning, *XV Intern. Geol. Congr.*, C.R., II, 1930, Tab. 1.
48. Erongo Granite, Erongo, South-West Africa. H. Cloos, *Beitr. Erf. D. Schutz.*, 1919, No. 17.
49. Karroo Dolerite, Insiza, S. Rhodesia. Ferguson, *S.R.G.S.*, Bull. 27, 1934, 64.
50. Karroo Dolerite (undifferentiated, anhydrous, mean of 11), Karroo. Walker (unpublished).
51. Tholeiite, East Griqualand. Poldervaart, *T.R.S.S.A.*, 1946, xxxi, Tab. 3.

52. Pigeonite Tholeiite, East Griqualand (mean of 3). Poldervaart, *loc. cit.*, Tab. 3.

53. Olivine norite, Insizwa. Du Toit, *Ann. R.G.C. for* 1910, 111.

54. Bronzite picrite, Insizwa. Scholtz, *T.G.S.S.A.*, 1936, xxxix, 117.

55. Microgranite, Insizwa. Goodchild, *Inst. Min. Metal.*, Bull. 147, 1916, 1.

56. Granophyre, Hangnest, Calvinia. Walker and Poldervaart, *T.R.S.S.A.*, 1942, xxix, 297.

57. Dolerite-pegmatite (Gap-dyke), Butterworth. Mountain, *T.G.S.S.A.*, 1944, xlvi, 61.

58. Basaltic Kimberlite, De Beers. Wagner, *The Diamond Fields of South Africa*, 1914, 84.

59. Micaceous Kimberlite, Lion Hill. Wagner, *ibid.*, 110.

60. Melilite basalt, Sutherland. Wagner, *ibid.*, 105.

61. Melilite-nepheline basalt, Swartheuwel, Namaqualand. Taljaard, *T.G.S.S.A.*, 1936, xxxix, 308.

62. Eclogite (Griquaite), Premier Mine. Wagner, *loc. cit.*, 129.

63. Olivine basalt, Lamberts Bay, Clanwilliam. Nell and Brink, *Ann. Univ. Stellenb.*, 1944, xxii, Sect. A, 56.

64. Foyaite, Granitberg, Lüderitz. Kaiser, *Die Diamantenwüste Südwest-Afrikas*, 1926, Bd. i, 304.

65. Nepheline syenite-porphyry, Pessene, Port. E. Africa. Young, *T.G.S.S.A.*, 1921, xxiii, 106.

66. Nepheline phonolite, Klein Spitzkop, Rehoboth. De Kock, *T.G.S.S.A.*, 1933, xxxvi, 85.

For further information see A. L. Hall, " Analyses of Rocks, Minerals, Ores, Coal, Soils, and Waters from Southern Africa," *Union S.A.G.S.*, Mem. 32, 1938.

APPENDIX.—*Table of Rock Analyses*

Number*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO_2	45·17	46·68	49·78	37·75	28·07	70·31	78·61	68·23	70·63	71·37	22·20	40·25	53·00	54·85	70·19	68·76	70·36
TiO_2	0·65	0·91	1·01	..	tr	0·30	..	0·71	0·61	0·34	0·10	1·57	..	0·95	0·70	0·68	0·38
Al_2O_3	11·67	13·08	13·42	..	1·95	13·87	7·76	15·46	14·34	15·26	62·90	18·57	19·70	15·15	12·05	16·16	14·68
Fe_2O_3	0·43	1·47	1·92	12·10	0·20	0·70	4·51	1·43	0·32	0·37	1·30	11·00	10·93	1·30	3·65	0·89	0·39
FeO	10·91	9·91	11·58	..	5·87	2·38	1·69	1·41	2·20	2·00	1·40	10·72	2·83	9·60	3·20	1·63	2·92
MnO	0·16	0·16	0·22	..	0·10	0·05	..	0·05	0·04	0·04	tr	0·47	tr	..	0·13	0·06	0·03
MgO	17·92	6·02	7·00	42·29	20·52	1·46	0·90	0·70	0·56	0·89	tr	2·02	4·00	4·30	0·12	1·02	1·24
CaO	7·47	10·15	10·76	..	11·58	3·60	2·60	2·31	2·04	1·87	6·00	6·94	7·20	7·80	0·12	2·04	1·92
K_2O	0·36	0·72	0·98	..	0·23	2·54	1·74	3·93	5·59	3·02	1·10	1·08	0·79	1·50	5·02	5·17	4·64
Na_2O	1·27	1·32	2·26	..	0·44	3·51	2·10	4·43	3·02	4·13	2·20	3·81	0·82	3·05	4·07	3·39	2·35
P_2O_5	0·18	0·10	0·18	..	0·15	0·23	tr	0·37	0·25	0·28	..	0·54	tr	..	0·13	0·13	..
S & FeS_2	..	0·13	0·04	..	0·08	0·07	..	..	..	..	..	0·56	0·25	..	..	0·03	..
H_2O+	3·45	3·15	0·81	5·70	0·24	0·58	..	0·49	0·40	0·07	3·30	1·12	..	1·40	0·31	0·25	0·74
H_2O-	0·42	0·20	0·13	..	0·12	0·13	..	0·21	0·09	0·05	..	0·09	..	..	0·05		0·18
CO_2	..	5·72	..	1·80	28·14	0·28	..	..	..	0·46	..	..	..	..	..	..	..
Total	100·06	99·72	100·09	99·64	97·49	100·01	99·91	99·83	100·09	100·15	100·50	100·28	99·57	99·80	99·74	100·21	99·83
Sp. Gr.	2·97	2·88	3·07	2·80	3·08	2·71	2·71	..	..	2·72	..	..	2·86	..	2·73	..	..

* For explanation of numbers (1-17) see p. 577.

Number*	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
SiO_2	53·95	48·25	49·45	52·7	50·70	55·30	41·20	32·16	52·28	55·16	55·00	69·20	75·84	74·10	72·56	74·35	60·24
TiO_2	0·90	0·05	0·05	0·15	0·20	0·10	0·25	0·95	0·43	..	..	0·65	..	0·20	tr	0·15	0·94
Al_2O_3	9·55	30·60	21·80	21·5	17·90	2·20	1·20	4·17	15·26	2·04	16·83	12·30	11·14	13·25	13·36	13·35	18·54
Fe_2O_3	0·80	0·90	nil	0·5	1·30	0·45	7·20	4·80	0·45	0·74	10·19	3·30	4·68	1·75	0·95	1·35	0·54
FeO	11·40	0·95	4·45	5·8	3·80	10·05	8·20	38·75	11·43	7·60	3·60	3·60	0·01	0·75	1·87	1·10	2·36
MnO	0·15	nil	..	..	..	0·15	0·10	0·37	0·31	0·17	..	..	tr	..	0·05	0·05	0·00
MgO	9·45	0·65	11·05	4·2	10·40	29·80	34·40	15·36	6·55	32·05	5·16	0·20	0·27	0·15	0·61	0·45	0·76
CaO	8·50	17·75	12·45	12·6	9·80	1·80	1·35	1·96	9·73	1·54	5·91	1·30	1·04	1·10	1·63	0·85	2·29
K_2O	1·50	0·10	0·05	0·3	0·30	tr	0·30	..	1·25	0·12	0·90	4·95	3·92	5·00	5·05	2·90	5·44
Na_2O	0·95	0·60	0·90	2·1	2·00	0·30	0·20	1·25	1·75	0·20	1·00	3·25	2·69	3·40	3·22	5·10	6·59
P_2O_5	0·15	0·25	0·20	0·2	0·05	0·20	..	n.d.	0·05	..	0·67	..	tr	tr	tr	0·10	0·27
S & FeS_2	..	..	..	..	..	..	0·05	..	0·11	..	0·23	..	..	..	0·04	..	0·13
H_2O+	2·30	0·25	0·30	0·05	1·00	nil	5·20	n.d.	0·05	0·22	..	0·70	0·64	0·45	0·80	0·30	0·50
H_2O-	0·15	0·15	0·10	..	0·03	0·10	0·25	n.d.	0·06	0·22	..	0·30	0·02	0·15	0·09	0·15	0·72
CO_2	..	nil	..	..	..	..	..	..	..	0·08	..	..	tr	..	..	..	0·43
Total	99·75	100·50	100·60	100·80	99·75	100·65	100·20	99·77	99·71	100·14	99·49	99·75	100·25	100·40	100·23	100·20	99·75
Sp. Gr.	..	2·74	2·92	2·87	2·92	3·34	3·01	..	3·00	3·31	2·77	..	2·63	2·62	..	..	2·64

* For explanation of numbers (18-34) see pp. 577-8.

APPENDIX.—*Table of Rock Analyses* (continued)

Number*	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
SiO_2	56·12	55·50	58·05	55·45	62·60	49·45	46·10	50·75	49·81	49·02	42·2	72·05	66·65	76·62	50·76	52·2	53·52
TiO_2	0·46	1·39	1·02	1·13	..	0·82	2·57	1·15	2·94	3·39	1·9	..	1·11	tr	0·80	1·3	0·88
Al_2O_3	19·62	19·87	18·62	17·80	16·58	16·47	22·25	13·80	13·79	10·03	8·95	12·79	11·69	11·97	13·41	14·9	13·68
Fe_2O_3	2·32	3·34	1·63	5·90	5·00	2·31	10·12	4·65	3·27	1·82	8·65	3·57	6·70	0·44	1·20	1·1	1·76
FeO	0·90	0·76	2·89	0·72	2·80	8·23	3·62	6·20	9·14	10·51	7·5	0·83	1·24	1·59	9·05	9·8	9·85
MnO	..	0·60	0·06	..	tr	0·16	..	0·10	0·18	0·46	0·15	..	0·10	..	0·22	0·3	0·21
MgO	0·13	0·28	0·68	0·14	4·20	8·08	2·90	7·10	5·35	12·23	8·9	0·47	0·96	0·11	11·10	7·1	6·26
CaO	2·07	1·63	2·29	1·90	4·40	10·12	5·60	8·90	10·77	7·72	9·8	1·98	2·40	0·62	10·18	9·9	9·97
K_2O	4·17	5·41	5·79	4·69	1·80	1·47	1·53	0·85	0·75	1·24	1·35	4·46	3·54	5·33	1·40	0·9	0·77
Na_2O	9·50	9·91	7·14	9·71	2·10	1·89	3·41	2·85	1·95	1·59	6·0	2·60	2·81	2·81	1·23	2·2	2·11
P_2O_5	..	..	0·01	..	0·37	0·24	..	0·20	0·49	0·16	0·9	..	0·24	0·11	0·10	0·2	tr
S & FeS_2	..	0·31	0·12	..	0·17	0·02	..	..	0·07	..	..	..	..	0·05	..	..	..
H_2O+	2·50	0·94	1·21	2·64	..	0·76	0·85	2·35	0·74	1·23	2·8	0·95	1·75	0·30	0·25	..	1·18
H_2O-		0·24	0·30		..	0·11	1·45	1·85	0·79	0·48	1·6	..	0·72	..	0·19	..	..
CO_2	0·80	..	..	..	..	tr	..	..	0·06	..	..	..	..	..	..	..	..
Total	99·59	100·18	99·81	100·80	99·62	100·13	100·40	100·75	100·10	99·88	100·70	99·7	99·91	99·94	99·89	99·9	100·19
Sp. Gr.	..	..	2·66	..	2·69	..	..	..	2·95	..	..	..	..	..	3·03	..	..

* For explanation of numbers (35-51) see p. 578.

Number*	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66		
SiO_2	53·11	50·66	40·40	72·90	65·14	50·83	30·95	31·80	31·17	34·45	44·91	46·32	58·84	46·16	52·59		
TiO_2	0·97	0·33	0·36	0·30	0·46	3·34	2·34	1·40	2·96	5·21	0·46	1·38	0·39	0·44	0·14		
Al_2O_3	14·64	4·42	2·76	12·42	14·92	15·50	4·17	3·41	6·25	8·99	17·15	15·87	19·19	23·32	21·78		
Fe_2O_3	2·61	6·85	4·15	1·20	1·18	1·09	6·16	5·19	3·22	6·20	1·68	4·97	2·92	4·72	2·07		
FeO	8·58	6·84	8·49	1·23	5·04	10·91	2·66	3·48	9·64	8·25	6·45	7·47	1·90	1·40	1·39		
MnO	0·23	..	0·18	tr	0·04	0·08	tr	..	..	0·26	..	0·14	0·03	..	0·02		
MgO	5·88	25·77	36·77	0·72	2·17	3·22	32·30	24·69	19·90	17·22	14·27	7·17	0·90	1·80	0·66		
CaO	9·58	3·30	1·75	2·35	2·49	8·96	8·92	10·04	17·76	11·47	11·28	10·31	1·01	4·55	2·43		
K_2O	0·86	0·35	1·35	8·60	3·38	1·92	1·61	4·32	2·51	1·31	0·89	1·12	5·48	4·96	5·81		
Na_2O	2·26	1·15	1·06		2·70	2·58	0·35	0·29	2·03	1·85	1·01	2·48	7·70	6·44	8·74		
P_2O_5	0·03	0·06	..	0·11	0·20	0·19	..	1·49	1·69	0·97	..	0·39	..	..	tr		
S & FeS_2	..	tr	..	0·09	..	..	..	n.d.	..	0·54	..	..	..	..	..		
H_2O+	1·05	0·28	2·75	0·70	1·96	1·24	6·81	5·59	2·05	2·59	1·78	2·53	1·41	5·10	4·31		
H_2O-	0·12	0·12	0·02	0·20	0·39	0·14	0·55	0·63	0·44	0·54			0·25	0·40	0·11		
CO_2	..	..	..	..	tr	0·10	2·54	7·65	..	0·33	..	..	..	..	..		
Total	99·92	100·13	100·09	100·82	100·07	100·10	99·36	99·98	99·62	100·08	99·88	100·15	100·02	99·29	100·05		
Sp. Gr.	..	2·95	..	2·56	..	2·92	2·835	..	3·12	3·12	..	..	..	..	2·53		

* For explanation of numbers (52-66) see p. 579.

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