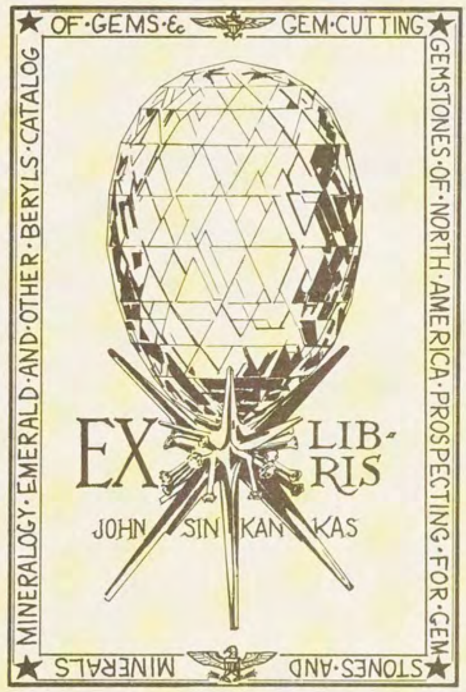
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27. HEFT. BAND VII. 7a.

HANDBUCH
DER
REGIONALEN GEOLOGIE

HERAUSGEGEBEN VON

PROF. Dr. G. STEINMANN UND PROF. Dr. O. WILCKENS
BONN BONN

VII. BAND. 7a. ABTEILUNG.

THE UNION OF SOUTH AFRICA

by

A. W. ROGERS, A. L. HALL, P. A. WAGNER and S. H. HAUGHTON

With 53 figures and 3 plates

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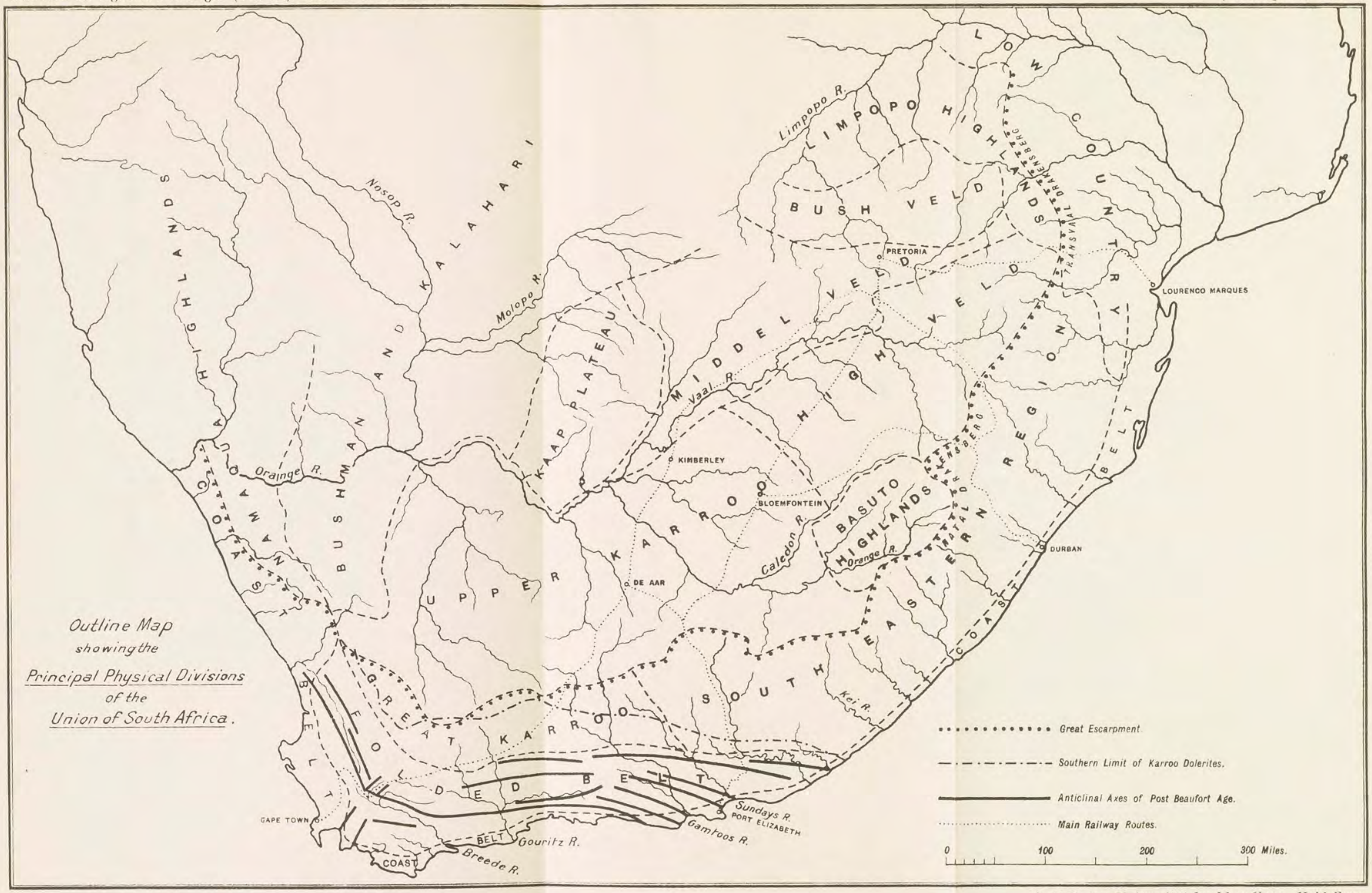
Anhang. Allgemeines Orts- u. Sachverzeichnis, Wörterbuch der Fachausdrücke.

Die Verfasser sind allein für den Inhalt ihrer Abschnitte verantwortlich.

Verzeichnis der einzelnen Hefte mit Preisen siehe dritte Umschlagseite.



Outline Map showing the Principal Physical Divisions of the Union of South Africa.

Carl Winters Universitätsbuchhandlung, Heidelberg.

The Union of South Africa.

By

A. W. Rogers, A. L. Hall, P. A. Wagner and S. H. Haughton.

Preface.

At the invitation of the Editors of this Series, the following description of the formations and mineral deposits in the Union of South Africa has been written by certain members of the staff of the Geological Survey of the Union.

Although for obvious reasons the geology of a young country like the Union of South Africa is not known with a degree of detail comparable to that reached in some older countries, where geological investigation has been carried on over a long period, sufficient reliable information has been gathered to justify the attempt of writing a general account of the geological and mineral resources from the point of view aimed at by the „Handbuch der Regionalen Geologie".

In South Africa systematic state-aided geological investigation was first realised in 1895 by the late Geological Commission of the Cape of Good Hope, an example very little later followed by the South African Republic in their appointment of a State Geologist. Somewhat later came the establishment of the Geological Survey of Natal and Zululand, maintained for a few years only, and of the Geological Survey of the Transvaal in 1903. As the result of Union, the Cape and Transvaal institutions became amalgamated into the Geological Survey of the Union in 1910. Thus regular geological mapping of the country has now been going on for over 30 years and has resulted in the survey of some 240000 square miles, i. e. approximately half the area of the Union. Much other official information is being obtained through the activities of other Government Departments, specially in connection with water supply problems, railway construction, etc., while many valuable data have been obtained by non-official investigations, notably by members of the Geological Society of South Africa and by geologists closely associated with the mining industry.

For these reasons it was felt that the progress in our geological knowledge of the Union has reached a stage where the issue of this volume would serve a useful purpose.

In view of the recent publication of a coloured geological map of the Union on the scale of one to a million, it was not thought necessary to include a similar map in this volume, where the outline maps for the various systems etc. are essentially diagrams of distribution only.

Dr. A. L. du Toit's volume on "The Geology of South Africa" also embraces the regions surrounding the Union and thus covers a distinctly wider field, but provides more detailed information on many parts of the subject as well as illustrations of important geological features in the country, and an excellent coloured map on the scale of one to five millions. The few points of classification in which our account differs from his are those on which recent field work has thrown new light; the chief of these is the relegation of the supposed western folded Nama beds of Namaqualand to pre-Nama formations.

The authors are greatly indebted to Dr. L. J. Krige who supplied the section dealing with the Pongola Series; to Dr. A. L. du Toit who has contributed the portion dealing with the Swaziland System in Natal and Zululand, and lastly to Prof. S. J. Shand for reading through the section describing the alkali rocks. A special word of thanks is due to the Cartographer, Mr. E. H. Banks, for his trouble in preparing the diagrams.

Pretoria. A. W. Rogers.

I. Morphology.

By

A. W. ROGERS.

(See frontispiece.)

a) Introduction and Table of Formations.

South Africa has an even coast-line which is short (2,801 miles = 3355.6 km) for the area of the land; it is essentially a country of high-lying plains, such as the Karroo, the Kalahari und the Transvaal Bushveld. The most marked physical feature is the Great Escarpment which surrounds the Interior Plateau at distances from the coast ranging from 50 to 250 miles (80—400 km); the surface rises abruptly at this escarpment, which places more or less difficulty in the way of travel to the interior from the west, south and east. The traveller from Cape Town, Mossel Bay or Port Elizabeth has to cross one or more ranges of folded rocks before reaching the plains below the Great Escarpment. These mountains, conveniently called the Cape Ranges, are the only mountains formed by crustal folding of post-Palaeozoic date in the country, but the Lebombo Range, on the east, is, so far as we yet know, a monocline, also of post-Palaeozoic date.

Inland of the Cape Ranges we reach plains cut in flat or gently inclined rocks with occasional steep, flat-topped hills, and the Great Escarpment rises from the plains as the dissected edge of gently inclined strata forming the greater part of the interior. The Cape Ranges extend from the Olifants River in the west to the Great Fish River in the east, and the approaches to the interior beyond those limits have more uniform grades than those between them.

The surface of the interior is largely made of gently inclined beds, and the greater part of them belongs to the Karroo system dating from late Carboniferous to Triassic times, but these Karroo strata are thickest in the south and east, and the further inland we go the more frequently we meet with pre-Palaeozoic rocks uncovered by removal of the Karroo beds. In the far interior the topography is, broadly speaking, of Carboniferous date, and it owes its preservation largely to the resistant character of the pre-Palaeozoic rocks as compared with the softer Karroo beds which still partly bury them.

The rivers of South Africa are steeply graded; there are none that are navigable by ocean-going craft, and the grade of those rivers which rise on the Great Escarpment beyond the limits of the Cape Ranges is particularly steep. The rivers draining the Interior Plateau eventually reach the ocean by way of the Orange or Limpopo Rivers.

The oldest known rocks in South Africa are sediments of various kinds and volcanic flows; remnants of such rocks in the form of fibrolite-gneiss, granulites, marbles, amphibolites and other schists occur enclosed in granite and gneiss. There is no sign of a beginning of the sedimentary record. In South Africa, as in all great regions yet explored, there are great bodies as well as undigested shreds of what probably were ordinary sedimentary and volcanic rocks lying in gneiss or granite below the earliest recognizable base of a stratified formation in the same region; often the partly digested shreds can be shown with much probability to have been parts of a succession of strata preserved in the same district and retaining characters by which the origin of such rocks is recognized.

The following statement in tabular form gives the succession of formations and the chief incidents that have been recognized in the past history of the sub-continent. It may be mentioned here that the term Swaziland System is used for all the sediments and volcanic rocks known, or believed, to be older than the Witwatersrand System, but that the inter-relation of many of the sub-groups is not known. It should also be stated that the Cambrian formation has not been identified in South Africa, and that the oldest fossils in the country yet determined are of Devonian age.

Table of Formations.

			Stratified Formations	Maximum Thickness	Igneous Intrusions.	Earth Movements.
Cainozoic			Recent and sub-recent sands, gravels, tufas, ironstones, and surface quartzites; raised beaches	Over 300 ft.		Depression of coast region, giving rise to lagoons. Uplift of whole of South Africa.
			Marine inshore beds of Namaqualand, Alexandria, Addo, Bredasdorp, and Zululand; lignites of Knysna; Kalahari beds	Small		
Mesozoic	Cretaceous System		Need's Camp Series (Danian)	—	Caldera of Pretoria Salt Pan. Volcanic pipes and fissures of kimberlite and melilite-nepheline basalts	Uplifts. Encroachments of sea on south-east coast. Faults in region of southern ranges, Limpopo valley and Orange River. Encroachments of sea over part of area where southern ranges exist.
			Umzamba Series (Senonian); Pondoland, Umkwelane Hill; shelly limestones and conglomerates	50 ft.		
			False Bay (Zululand) and Manuan Creek (Cenomanian), clayey limestones	50 ft.		
		Uitenhage Series (Neocomian)	Sunday's River beds; marine clays and limestones Wood beds; sands and clays, Enon beds; sands, clays, and conglomerates	Over 4000 ft.		
	Karroo System.	Stormberg Series (Triassic)	Drakensberg or volcanic beds; basaltic and andesitic lavas and tuffs of Quathlamba, Springbok Flats, Lebombo rhyolites, and ultrabasic lavas of the Limpopo valley?	4000 ft.	Intrusion of basic rocks throughout the Union	Emergence of land over Karroo region, following the restriction of area of deposition during the rise of the southern ranges.
			Cave sandstones of Quathlamba and Bushveld sandstones of Transvaal	800 ft.		
			Red beds; sandstones and shales	1600 ft.		
			Molteno beds; sandstones, shales, and conglomerate with thin coals in Cape Province	2000 ft.		
Palaeozoic		Beaufort Series (Permian and Trias)	Burghersdorp beds; shales and sandstones	3000 ft.		Mountain building in the south and west of Cape Province.
			Middle Beaufort beds; sandstones and shales	1000 ft.		
			Lower Beaufort beds; shales and sandstones	7000 ft.		
			Ecca Series; shales and sandstones; coal in Transvaal and Natal	6200 ft.		
		Dwyka Series	Upper shales	800 ft.		Long period of depression and deposition in the south of the Union.
			Tillite	1400 ft.		
			Lower shales	1000 ft.		
	Cape System		Witteberg Series; shales and quartzites	2500 ft.		
			Bokkeveld Series; shales and sandstones; marine (Devonian) fossils in lower half	2500 ft.		
			Table Mountain Series; quartzitic sandstones and shales; tillite in Cederberg region	5000 ft.		Mountain building in Griqualand West, etc.
			Alkaline volcanic rocks of Pilandsberg	—	Syenite dykes and sills. Alkaline intrusions of Pilandsberg, Franspoort line, etc.	

	Stratified Formations		Maximum Thickness	Igneous Intrusions	Earth Movements
Waterberg System.	Waterberg; sandstones, shales, and conglomerates	Matsap Series of GriqualandWest, etc.; quartzites, conglomerates, lavas, and tuffs	5000 ft. Over 7000 ft.	Intrusion of Bushveld Complex. Intrusion of younger granites of the Cape Province	Mountain building in south and west of Cape Province. Long period of depression in the north, west, and south of the Union.
	In East.	*In West.*			
Transvaal System	Rooiberg Series; quartzites, shales, and lavas				
	Pretoria Series; shales, lavas, quartzites, and a tillite, ferruginous beds	Ibiquas beds	10000 ft.		
	Campbell Rand Series; dolomites, shales	Malmesbury beds	3500 ft.		Minor uplifts in Griqualand West, Bechuanaland, and Transvaal.
	Black Reef Series; quartzites, shales, and conglomerates	Nieuwerust beds	2,550 ft.		
Ventersdorp System	Pniel Series; lavas, tuffs, conglomerates, shales, and quartzites	? Koras Series of Kenhardt and Gordonia, lavas, sandstones, conglomerates	5000 ft.		
	Kuip Series; lavas, limestones, cherts, sandstones arkose	? Stinkfontein, Kaigas Numees and Groot Derm	—		
	ZoetliefSeries; acid lavas, shales, quartzites, conglomerates				
Witwatersrand System	Upper Witwatersrand beds	Kimberley-Elsburg Series; quartzites, grits, conglomerates, and shales Main-Bird Series; quartzites, grits, conglomerates, shales, and lavas	25000 ft.	Intrusion of basic dykes in S. Transvaal	Uplift over Witwatersrand
	Lower Witwatersrand beds	Jeppestown Series, chiefly shales Government Reef Series; quartzites, shales, ferruginous beds, grits, and thin conglomerates Hospital Hill Series; quartzites, shales, ferruginous beds, arkose			
Swaziland System (Inter-correlation unknown).	Pongola Series	Upper Pongola beds; shales, quartzites, and conglomerates Lower Pongola beds; quartzites, phyllites, lavas	—	Intrusion of Palabora Complex, and granites	Mountain building in north and west, followed by prolonged denudation.
	Kraaipan Series; schists, ferruginous cherts, and volcanic rocks				
	Abel's Kop beds	Schists, limestones, banded ironstones	—	Intrusion of gneisses, etc., of north and west of the Cape Province and the Transvaal and Natal	
	Kheis Series	Wilgenhout Drift beds; sedimentary and volcanic rocks Kaaien beds; quartzites and schists Marydale beds; sedimentary and volcanic beds			
	Moodies Series; ferruginous rocks, quartzites, schists, and conglomerates of Barberton and Pietersburg Districts		25000 ft.		
	Schists of sedimentary and volcanic origin in Namaqualand				

b) Physical Features and Geological Structure.

1. The Great Escarpment.

Wherever one approaches the interior, except by way of the Limpopo Valley, one has to ascend a steep gradient before reaching the highlands of the Transvaal, Orange Free State, Basutoland, the Upper Karroo or Bushmanland. The distance from the coast at which the steepest slope begins decreases fairly regularly from 250 miles (400 km) in the north-east, south of the Zoutpansberg, to less than 50 miles (80 km) in Namaqualand. The position of the foot of the steep slope does not coincide with a contour line but rises with the height of the top of the escarpment, which reaches its maximum at Giant's Castle, some 10,600 feet (3230 m) above the sea in the Natal Drakensberg. The rise of the summit line increases more rapidly than that of the base, so that the cliffs are highest where the summit line reaches its greatest altitude. There are two regions where considerable reversals of slope are found on the way inland from the coast; in the east, where the Lebombo Range and the Barberton Mountain Land have to be traversed, and in the south and south-west, from near the mouth of the Great Fish River to the latitude of Van Rhyns Dorp, a distance of 600 miles (965 km), where the Cape Ranges lie between the coast and the escarpment.

Broadly speaking the Great Escarpment is the watershed between the rivers leading directly to the ocean and those which enter it by way of the Orange and Limpopo; the exceptions to the general rule will be noticed presently.

Commencing in the north-east, we find (see Frontispiece) the first trace of the escarpment within the Union on the southern flank of Zoutpansberg, where the edge of the Pietersburg plateau, deeply cut into by the head streams of the Pafuri, Shingwedzi and Letaba Rivers, meets the Zoutpansberg about Belim. The Zoutpansberg itself stretches some 50 miles to the east-north-east beyond the edge of the plateau, gradually sloping down to the northern end of the Lebombo Flats. The escarpment in this region is made of granite and gneiss as far south as Letaba Point and Wolkberg, which are on the Black Reef quartzites where that formation is thickest and where the range formed by it swings round from north-east to south-east and south, forming the cliffs of the escarpment (here known as the Transvaal Drakensberg) for 120 miles (194 km) as far as the Carolina district. Here the Karroo beds appear at the edge of the Highveld, lying at first on the Black Reef Quartzites, and, after the latter have thinned out by pre-Karroo erosion, on the granite and older sedimentary rocks below. In this region the escarpment is indented by the headwaters of the Komati and Usutu Rivers, and it lacks a strong, nearly horizontally bedded formation at its summit, for the base of the Karroo system, though strengthened here by sheets of dolerite, is weak compared with the quartzites of the Drakensberg to the north and the thick sandstones and the volcanic rocks of the Quathlamba to the south. The part taken in the structure of the escarpment by the Karroo formation increases southwards, and in the course of the hundred miles to the valley of the Buffalo River below Charlestown it comes to form the whole of it. So far the Ecca and Lower and Middle Beaufort beds alone appear on the escarpment, but 80 miles (128 km) to the south, in the Tugela basin, the Upper Beaufort and the Stormberg series come in, and the escarpment increases in height and is known as the Quathlamba or Natal Drakensberg, with the highest points in the country on its crest. The Stormberg series, with the great pile of volcanic rocks at the top, forms the whole range of cliffs for some 230 miles (370 km), as far as Xalanga Peak, where the lavas disappear from the ridge and the escarpment is made of the sediments below, the Cave Sandstone, Red Beds, Molteno Beds and dolerite sheets, with an increasing thickness of Beaufort beds as it is followed westwards toward Bamboes Berg, where the Molteno beds alone of the Stormberg series remain on the summit. In this region the escarpment is deeply embayed by the head-streams of the Great Fish River, and it is continued westwards in the Sneeuwbergen, while Beaufort beds, capped by thick, gently inclined intrusive sheets of dolerite, form its face for some 230 miles (370 km). Near the head-stream of the Dwyka River the dolerites disappear, and the thick sandstones of the Lower Beaufort form the upper part of the escarpment for 80 miles (128 km) in the Komsberg and the Roggeveld Berg. The escarpment trends north-west from Komsberg, and twelve miles northwest of Verlaten Kloof, which separates Komsberg from the Roggeveld Berg, dolerite sheets reappear on the crest and maintain that position for more than 70 miles (112 km), as far as the Hantam. In the Roggeveld the Beaufort beds disappear from the edge, the Ecca beds and dolerite sheets forming the whole of the escarpment, while 20 miles (32 km) beyond Hantam the Dwyka series and thin sheets of dolerite, with an occasional outlier of Ecca beds, constitute its upper part. For 40 miles (64 km) in this region the escarpment is divided into two portions by a step increasing to 20 miles (32 km) in width southwards from Drooge Houts Berg; the lower, or western, part is the Bokkeveld escarpment, a cliff of Table Mountain Sandstone of which the beds dip gently eastwards and merge southwards into the eastern limb of the Cederberg anticline in the region where the folding which gave rise to the Cape Ranges died out. The step between the Bokkeveld and the higher part of the escarpment east of it is occupied by the valleys of the Draaikraal, Oorlogs Kloof, Doorn and Kromme Rivers, and the prominent dolerite-capped Klip Rug Kop stands on it. Beyond the north end of the Bokkeveld the base of the Karroo system forms the top of the escarpment, lying at first on gently inclined beds belonging to the Nama system and then, north of a pre-Karroo fault on Ezel Kop Vlakte, on pre-Nama granite and gneiss. The granitic rocks then form the greater part of the escarpment and the Dwyka disappears, but the outliers of the Dwyka series of Langeberg and Hartslag Kop bear witness to a former covering of Karroo rocks far north of their present limit. With these exceptions granite and gneiss form the whole escarpment for 120 miles (194 km), as far as the valley of Buffels River at Spektakel. Nearly a third of this distance is taken up by Kamiesberg, the western extension of the granite floor of Bushmanland which rises to 5,510 feet (1679 m) in Ezel Kop. At Spektakel the base of the Nama system, the hard Nieuwerust quartzite, caps the escarpment for 30 miles (48 km), and then the older granite again is the only component for another 30 miles (48 km); thereafter, as far as the Orange River 50 miles (80 km) distant, the escarpment is continued in folded pre-Nama beds, older granite, and, for 17 miles (27 km), through the middle of the granite of Kuboos.

There is a broad similarity in the structure of the escarpment in the east and west, for on each side pre-Nama granite and gneiss form the whole of it for many miles before the Nama and Karroo formations take an increasing share in it. The greatest elevation is in the east, where the Karroo formation reaches a great thickness and where the Stormberg series reaches its greatest development. The crest-line averages perhaps 6000 feet (1800 m) in the east as compared with 3000 feet (900 m) in the west. For about 1120 miles (1800 km) out of 1400 (2250 km) within the Union the escarpment is capped by hard rocks dipping at low angles towards the interior. Parts of the crest now made of granite or gneiss were formerly covered by the landward dipping rocks, probably the whole 280 miles (450 km) of the escarpment now wanting this cap were so covered. In the Kamiesberg region the Karroo beds may have been removed by denudation in Cretaceous or early Tertiary times, for in Bushmanland to the east no Karroo beds are preserved between the floor of ancient gneiss and the deposits containing bones of Dinosaurs filling part of the Henkries valley.

The escarpment has been examined in some detail for 1200 miles (1930 km) and there is little doubt that in the unsurveyed gap of 200 miles (320 km) between the Molteno and Aberdeen districts it is independent of faults and folds, as it is throughout the rest of its extent within the Union. A striking instance of its independence of structure in the pre-Karroo rocks is to be found in Namaqualand, where it cuts across the pre-Nama granite of Kuboos. The only other large body of rock which strikes across the trend of the escarpment is the Zoutpansberg, which completely interrupts it in the extreme north-east.

2. The Interior Plateau

is limited by the Great escarpment. No great ranges stand on its surface, for the local differences in level seldom reach 3000 feet (900 m), and they only attain that figure amongst the head-waters of the Orange River and where that river has cut a deep valley through the Richtersveld within 100 miles (160 km) of its mouth. The surface of the interior has not been disturbed by folding on any considerable scale since Palaeozoic times, and the few faults known to have affected it during the same period are found in the central and northern Transvaal and in the country less than 100 miles (160 km) inland from the mouth of the Orange River. Vertical movements on a great scale have affected the interior and the rest of the sub-continent, and it is to these movements of post-Karroo (i. e. post-Triassic) age that the present general high altitude of South Africa is due.

The Interior Plateau falls directly into two parts separated by a sinuous line running north-eastwards from the south-western corner of Bushmanland to the Carolina district in the Transvaal. South of this line the whole region is occupied by gently inclined or flat Karroo sediments, lavas and the intrusions of dolerite which invaded them in late Karroo times. North of it there are still great outliers of the Karroo formation, but these beds have been removed from yet larger areas where the pre-Karroo (i. e. Carboniferous) topography has been exposed and no doubt in some places modified to a considerable extent by post-Karroo denudation.

The Interior Plateau can be further subdivided into several regions according to their surface characters which are dependent on geological structure and past and present climates.

I. The High Veld embraces the Southern Transvaal and a large part of the Orange Free State lying from 4500 (1340 m) to 6000 feet (1830 m) above the sea and occupied by Karroo beds horizontally disposed with extensive sills of dolerite amongst them. In the west there are inliers of the Witwatersrand and younger pre-Cape rocks. The surface is generally flat or undulating, but the pre-Cape rocks make hilly ground, especially in the Zuikerbosch Rand and Venterskroon. These ancient rocks have high dips, but they do not rise to heights much over 6000 feet (1830 m) and at about that level they are cut off by a pre-Karroo peneplain, which had been dissected to depths of about 1000 feet before the valleys were filled in with the deposits of the Karroo formation. Part of this very ancient plain emerges from under the Karroo beds on the high ground east of Nigel, and the bold escarpment of the Witwatersrand which overlooks the Highveld south of Nigel is a pre-Karroo feature.

Pans are an anomalous feature in the Highveld, for the rainfall averages more than 25 inches (0.625 m). The pans often retain water all the year and when they dry up vegetation covers their floors. They were probably formed at a period geologically recent when the rainfall was less than it now is. The region is entirely within the drainage basin of the Vaal River; it is mainly grass veld, indigenous bush being confined to the hills and the banks of rivers.

II. The Basuto Highlands are the mountainous country about the headwaters of the Orange River. They are cut out of the highest group of the Karroo formation, the Stormberg series, lying nearly flat; the region has been very deeply eroded, and the highest points in the country are on the watershed between the Orange catchment and the streams flowing to the Indian Ocean. The chief character of the region is the series of mountain ridges made of the dark volcanic beds, 4000 feet (1220 m) thick lying on the massive, pale-coloured Cave Sandstone.

III. The Upper Karroo. The Highveld and Basuto Highlands grade west- and south-westwards into the Upper Karroo through plains becoming more and more extensive. It is made almost entirely of flat-lying Karroo beds with intrusions of dolerite which form rough, dark ridges on the plains as well as cliffs round the table shaped hills. The rainfall drops from some 25 inches (0.625 m) in the east to 5 (0.125 m) in the west, and in the same direction superficial deposits of limestone become more and more abundant where the ground is flat. The streams are intermittent and the soil thin except in alluvial valleys. Pans are abundant, particularly towards the edge of the Karroo formation, and in the low-grade valleys of Carnarvon, Kenhardt and Calvinia great "vloers" tracts of flat ground covered with brackish silt have developed. There is a gradual change westwards from grassveld to scrub, and in places the scrub is advancing eastwards at the expense of grass. The region is greatly affected by soil-erosion and the lowering of the ground water level owing to overstocking in this area of intermittent drought.

IV. The Namaqua Highlands are formed by the outcrop of the pre-Cape rocks underlying the Karroo beds of the interior; they are the rocky western edge of the plateau, and rise to over 5000 feet (1524 m) in Kamiesberg, where there are a few short perennial streams. The rainfall is scanty, from 5 inches (0.125 m) or less to 15 (0.375 m) over a very small area in the highest part of the region.

V. The Kalahari and Bushmanland are alike in having a low rainfall (5 to 10 inches = 0.125 to 0.250 m), practically no surface drainage, a general covering of sand through which rise hills of the island-mountain type, i.e. hills with straight and steep profiles with abrupt change of slope at the bottom. The Orange River has cut its valley across the region, but it receives no permanent addition from it. The mountains, Langeberg and Korannaberg, are the remains of extremely ancient folded ranges which were perhaps completely buried under Karroo beds and which now exhibit the forms they had in Carboniferous times, owing to the removal of the unconformable cover. Flat lying Karroo beds still cover the greater part of the region under the sand, which has been accumulating probably since late Cretaceous times. There is practically no outflow; water in the rivers from the country with higher rainfall to the east rarely traverses the Kalahari, chiefly owing to absorption of water by the Dolomite region exposed through denudation of the overlying Karroo beds about the headwaters, and absorption of the local rainfall by sand throughout their length. A marked character of the region is the general cover of grass, even where the sand forms dunes. Bare patches of sand are rarely seen; they lie chiefly along the Orange River where the veld has been destroyed by overstocking. These facts point to increased precipitation during recent times.

VI. The Kaap Plateau lies between the Langebergen on the west and the Campbell Rand escarpment on the east. That escarpment, like the meridional ranges, the Asbestos mountains and those of the Kalahari, is of pre-Karroo age. It ranges in height from about 4000 (1220 m) to slightly over 6000 feet (1830 m) on a few hill tops, and a general character is due to the existence of the wide plains cut in gently inclined Dolomite (Campbell Rand series), in which the drainage is chiefly through underground passages. The rainfall ranges from about 5 to 20 inches (0.125 to 0.5 m).

VII. The Middle Veld extends north-eastwards from the escarpment bounding the Kaap Plateau to the Central Transvaal, having the Highveld to the south and the Bushveld to the north. Though it includes a long strip of Karroo beds in the Dry Harts-Vaal valley and outliers further east, it is in the main a region where the landscape of Carboniferous times has been almost completely exposed by the removal of the Karroo deposits. This pre-Karroo surface is flat in the west, with a rather sudden drop into the old Kaap Valley which, having been scoured by a glacier or thickened part of the southward moving land ice, was refilled in late Dwyka times. The flat country of the south-western Transvaal is part of the ancient plain, but eastwards the Gatsrand and Magaliesberg are hill ranges of that age apparently cut out of an extensive peneplain of which the Zuikerboschrand of Heidelberg and the Witwatersrand were also parts in times considerably pre-dating the Dwyka formation. The Dolomite country of Pretoria, Rustenburg, Marico and Lichtenburg is characterised by its frequently underground drainage, a feature which has developed as the Karroo beds were stripped from its surface. The rainfall increases eastwards from about 15 to 30 inches (0.375 to 0.750 m), and in height it ranges from 3000 (900 m) to nearly 6000 feet (1800 m) above the sea.

VIII. The Bushveld of the central Transvaal lies chiefly on igneous rocks of the Bushveld Complex and the sedimentary beds of the Transvaal system which dip under it on all sides. It is an undulating country with moderate (15 to 25 inches = 0.375 to 0.625 m) rainfall, but hills of the island-mountain type are conspicuous in the Pyramids north of Pretoria, in M'Phathlele's Location in the north-east, and Pilandsberg. The uppermost part of the Karroo formation, the Cave Sandstone overlain by lavas, the Bushveld Amygdaloid, still covers the large area called the Springbok Flats; the contrast in shape of surface between this and another large area (Basutoland) made of the same formations is due to the difference in the condition of the drainage; in the Bushveld the rivers, after leaving the Karroo rocks, traverse a belt of hard rocks which, except in the valleys, stand up as a range of mountains. The Karroo formation in the Bushveld is reduced in thickness as compared with the same beds in the Karroo, and the region is affected by post-Karroo faulting, though the Karroo beds are folded very slightly if at all.

IX. The Limpopo Highlands are formed by the belt of high country separating the Bushveld on the north-west, north and east from the Limpopo valley and the Low Country. The Karroo beds have been completely stripped from it, and it is not yet known to what extent its general form and elevation is due to differential earth movements of post-Karroo date. The northerly dips in the Waterberg beds of Zoutpansberg are due pre-Karroo disturbances, as are those in the Drakensberg and Chunies Poort ranges, but the considerable altitude (more than 2000 feet = 1600 m) of the hill tops over the base of the Karroo beds in the Waterberg flats and the Limpopo valley on the one hand, and in the Bushveld on the other, is in part due to post-Karroo faulting and bending.

X. The Low Country, ranging from 500 feet (150 m) to 3000 feet (900 m) above the sea, extends from the Waterberg Flats down the Limpopo Valley into the Lebombo Flats, the Murchison Range and Barberton, thus including country below the Great Escarpment which abuts against the southern flank of Zoutpansberg. Made chiefly of Archaean rocks, parts of which form island-mountains in the Murchison Range and the Limpopo valley, there are extensive areas of Karroo beds in the Waterberg Flats and the Limpopo valley; in the latter are also the possibly post-Karroo flows of soda-rich basic lavas, overlying the Bushveld Sandstone unconformably, and the area where they occur has been affected by trough-faulting of the same or later date than the lavas.

3. The Country below the Great Escarpment.

The great geological events which distinguish the structure of the country between the escarpment and the coast from that of the interior are the mountain folding of early Mesozoic date and the faulting and minor folds of late Mesozoic or early Tertiary age. For 600 miles (965 km) in the south and west the Cape and Karroo Systems are involved in repeated folds of considerable amplitude, and in the south the folds are often pressed together and overturned towards the north, and there are many small thrusts in the same direction. The remnants of the Cape formation with low dips in the Bokkeveld of Van Rhyns Dorp, on the west coast, in the Cape Peninsula and about Cape Agulhas suggest that the Folded Belt is a zone of folded strata surrounded on the west and south, as well as on the north, by country that was not appreciably folded.

From Cape Agulhas eastwards to Peddie the coast traverses the strike of the folded rocks in a long slant, and the pre-Cretaceous rocks near it have high dips, for they are part of the Folded Belt. From where the Folded Belt meets the shore in Peddie the coast is made of gently inclined rocks for 150 miles (240 km), but in Pondoland again there are remnants of rather steeply dipping beds about the mouth of the Umgazana River, the Molteno beds being found there with high southerly dips. The Molteno beds are not known to be affected by the Cape folds inland, and the recent discovery of what is probably the upper part of the Stormberg series, not folded or cleaved as are the Lower Karroo beds in contact with them across a fault, but occupying a down-faulted strip of country 100 miles (160 km) long inland of Algoa Bay, is strong evidence that the close folding and cleavage of the Cape and the lower part of the Karroo formation was completed in the Zuurberg region before the Cave Sandstone was deposited. Long before that discovery had been made, the pre-Molteno age of the folding in the southern ranges had been assumed on the evidence of quartzite boulders in the Molteno conglomerates which were supposed to have come from the Table Mountain or the Witteberg series, but the evidence was weak, and more weight lay in the avoidance of the Folded Belt by the dolerite intrusions so abundant in all the rocks to the north up to and including the Drakensberg volcanic beds. This indicated the pre-dolerite age of the folding, and we may now put back the date with confidence to the pre-Cave Sandstone period.

The existence of lithologically normal Molteno beds on the Pondoland coast is evidence against the persistence of the Cape folds eastwards under the sea as far as that region, as they should persist had there been an eastern range corresponding to the Cederbergen in the west; but the folding south of St. John's and the structure of Natal prove that post-Karroo disturbances made themselves felt in the east as far south as Pondoland, though they had a greater effect in the Lebombo. The great unconformity in Natal between the Cape and Karroo systems was due to the earlier disturbance of the Cape formation there, as in the Cederberg region in the west, than in the country south of the Karroo. The Cape folding itself probably began in late Carboniferous times in the Cederberg region, where the folds trend north-north-west, but they reached their maximum at some time during the Triassic period in the country south of the Karroo.

The submarine contour at about 100 fms. (182 m) which limits the Agulhas Bank lies 150 miles (240 km) south-south-east of Cape Agulhas, and from that point it approaches the continent more closely both to the north-west and north-east, especially in the latter direction. The 100-fms. (182 m) line runs approximately parallel to the west coast, which cuts across the minor western folds of the Cederberg group near the mouth of Olifants River, but in the east the line is still more discordant with the trend of the Cape folds than with the present coast. Thus the shape of the Bank gives no help in finding an outer, undisturbed platform of the rocks which build up the Folded Belt.

The country below the escarpment can be divided conveniently into four regions, as follows.

XI. The Great Karroo is the semi-arid country (average rainfall from 5 to 10 inches = 0.125 to 0.250 m) north of the Cape Ranges; its eastern limit may be taken along the valley of the Sundays River, east of which the increasing rainfall supports a less scanty vegetation, grass becoming more and more abundant towards the east. It is made entirely of gently inclined Karroo beds with many intrusions of dolerite north of a line stretching westwards from a point between East London and the Gualana River. In the west flat-topped hills and plateaux are conspicuous, and only in the extreme south is there a pronounced east-west grain where the beds begin to be affected by the Cape folds. Plains are frequent in the country immediately on the inland side of the folds, but they do not reach the size of the plains of the Interior Plateau because the river grades are steeper in the Great Karroo. The rivers all traverse the Folded Belt in deep gorges.

XII. The South-eastern Region is the seaward slope below the Great Escarpment from Graaf Reinet to the southern end of the Low Country. It is directly continuous with the Great Karroo, but the Folded Belt disappears between it and the coast in the Peddie district, beyond which the Lower Karroo beds reach the coast almost undisturbed as far as Pondoland. In Natal a wide belt of pre-Karroo beds appears in the axis of a low anticline flanked on the ocean side by remnants of Karroo beds. In the landward part of the region intrusions of doleritic rocks are very abundant, including the great masses of the Ingeli, Tonti, Insizwa and Mount Currie. With increasing rainfall towards the north-east the streams become permanent. They flow in deeply incised valleys and have in general steep grades, but there are many instances of long stretches of low grade with conspicuous meanders above falls or rapids over thick sandstones or sills of dolerite.

XIII. The Folded Belt is roughly 100 miles (160 km) wide in the south and less than that in the west where the folding is less intense. Individual fold-axes cannot be followed for great distances; they form, in plan, wide arcs concave to the south and west in the south and west respectively. The diagonal belt in which the two groups of folds meet, stretching from Karroo Poort[1] south-south-westwards to Cape Hangklip, is not on a sharp bend in the strike, but an area of conflict between the two directions of thrust, for there are diagonal ranges made of rocks with resultant strikes inclined to the two directions of thrust, from the west and from the south.

The unconformity at the base of the Dwyka north of Karroo Poort indicates that the Cederberg or western folds were initiated before the southern, but they are less intense, being broad and regular anticlines and synclines with little difference in dip on either side. The Table Mountain series is the chief mountain building rock owing to its massive and weather-resisting character and to the progress of denudation, although it forms the base of the 25000 feet (7620 m) of Cape-Karroo beds chiefly involved in the folding; in the east, where the amplitude of the folds decreases, the Witteberg beds, at the top of the Cape System, are the chief constituents of the mountains. The heights reached by the Table Mountain series in the west [6336 ft. (1931 m) at the Cederberg beacon] are less by about 1000 feet (305 m) than those in the Zwartebergen. The western ranges, from the Breede River valley northwards, are devoid of outliers of Cretaceous beds such as those which are an important element in the Folded Belt east of Breede River and south of the Zwartebergen.

The southern ranges fall into two main groups, the Zwartebergen on the north and the Langebergen 40 miles (64 km) to the south. The Zwartebergen bear the highest mountains [7627 ft. (2325 m) near Seven Weeks Poort], but the amplitude of the folds decreases rapidly towards the east. The Langeberg group commences as a wide simple anticline in the west near Worcester, but it becomes closely folded eastwards, and between the Knysna and Port Elizabeth it forms a belt of mountainous country 50 miles (80 km) wide with narrow infolds of Bokkeveld beds and, so far as is yet known, only one inlier of pre-Cape rocks, the long strip south of the Kouga Mountains. Throughout the Folded Belt the main ranges are anticlines,

[1] "Poort" is the South African equivalent of a "water-gap", "Pforte", or notch in a range of hills lying athwart the course of a river.

either complete or with the southern limb partly replaced by a normal fault. Synclinal ridges form a very small part of the region. The ranges as a whole date from late Carboniferous in the northwest to perhaps early Triassic, for the Lower Beaufort beds of Permian age are involved in the folding south of the Karroo. The highest parts of the ranges probably have been subject to erosion since Permian times, and the outstanding portions that have survived are made of the more resistant beds. Throughout the Folded Belt there are remnants of a peneplain up to some 2500 feet (760 m) above the sea. The plain slopes towards the sea and towards the nearest large valleys, and it extends at least from the Bathurst district to the Breede River Valley. It is of post-Cretaceous date. Possibly a still higher peneplain is represented by some flat surfaces cut across steeply dipping rocks at about 4000 feet (1220 m).

Within the Folded Belt there are several down-faulted areas of Cretaceous (Neocomian) rocks; the largest are those of Uitenhage and Oudtshoorn, and smaller outliers extend as far west as Worcester. These areas are bounded by faults on their northern sides, and the faults, even where straight, are not quite parallel to the strike of the rocks north of them, for the latter are often cut off obliquely. Towards the east the Gamtoos and Uitenhage faults are curved, being concave to the downthrow side. The Cretaceous beds usually dip towards the faults, and in the larger areas broad flexures are developed, but these folds never approach in magnitude the folds affecting the older rocks of the region. The date of the faults is post-Neocomian and earlier than the deposition of the Alexandria beds, possibly of Miocene age, which stretch unbroken across them.

The rainfall ranges from about 5 inches (0.125 m) near Prince Albert and Karroo Poort to over 70 inches (1.750 m) about the sources of the Berg River. The southwestern and southern rivers having their sources within the mountains have permanent flows, but the great rivers from the Karroo, the Gouritz, Gamtoos and Sundays, which traverse the Folded Belt in gorges, become a series of pools in times of drought.

XIV. The Coast Belt or low lying country immediately behind the shore is extensive in the north-east where there are wide stretches of late Cretaceous and Tertiary marine sediments, but it narrows to a mere strip through Natal and as far as Algoa Bay, where there are dune-covered areas around the mouths of the Sundays and Zwartkops Rivers. Westwards there are considerable areas of low-lying sandy country in the wider bays, but, excepting such places, the country rises steeply from the shore to heights generally less than 1000 feet (305 m), though cliffs occur at a few places only, such as the Knysna, Cape St. Blaize and Cape Infanta. West of Cape Agulhas wide areas of low country are found behind False, Table and St. Helena Bays. Northwards to the Orange River the rise inland is steeper and more uniform, and cliffs occur about Saldanha Bay, Baboon Point, Strand Fontein and beyond Port Nolloth. There are Tertiary and later marine deposits of beach type at intervals round the Cape coast, though little is yet known of them. In Uitenhage and Alexandria a Mio-pliocene fauna has been described from these beds at a considerable elevation above the sea and several miles from it.

The coast line cuts across all the pre-Tertiary structural lines in its neighbourhood, except perhaps in part of Natal, where it is parallel to some minor faults with downthrow towards the sea.

4. The Main Divide and Rivers.

The general rule that the Great Escarpment is the watershed between the catchments of the Orange and Limpopo in the Interior on the one hand and the shorter rivers rising on its steep face and running directly to the ocean on the other has an important exception in the north-east, where the Olifants River of the central

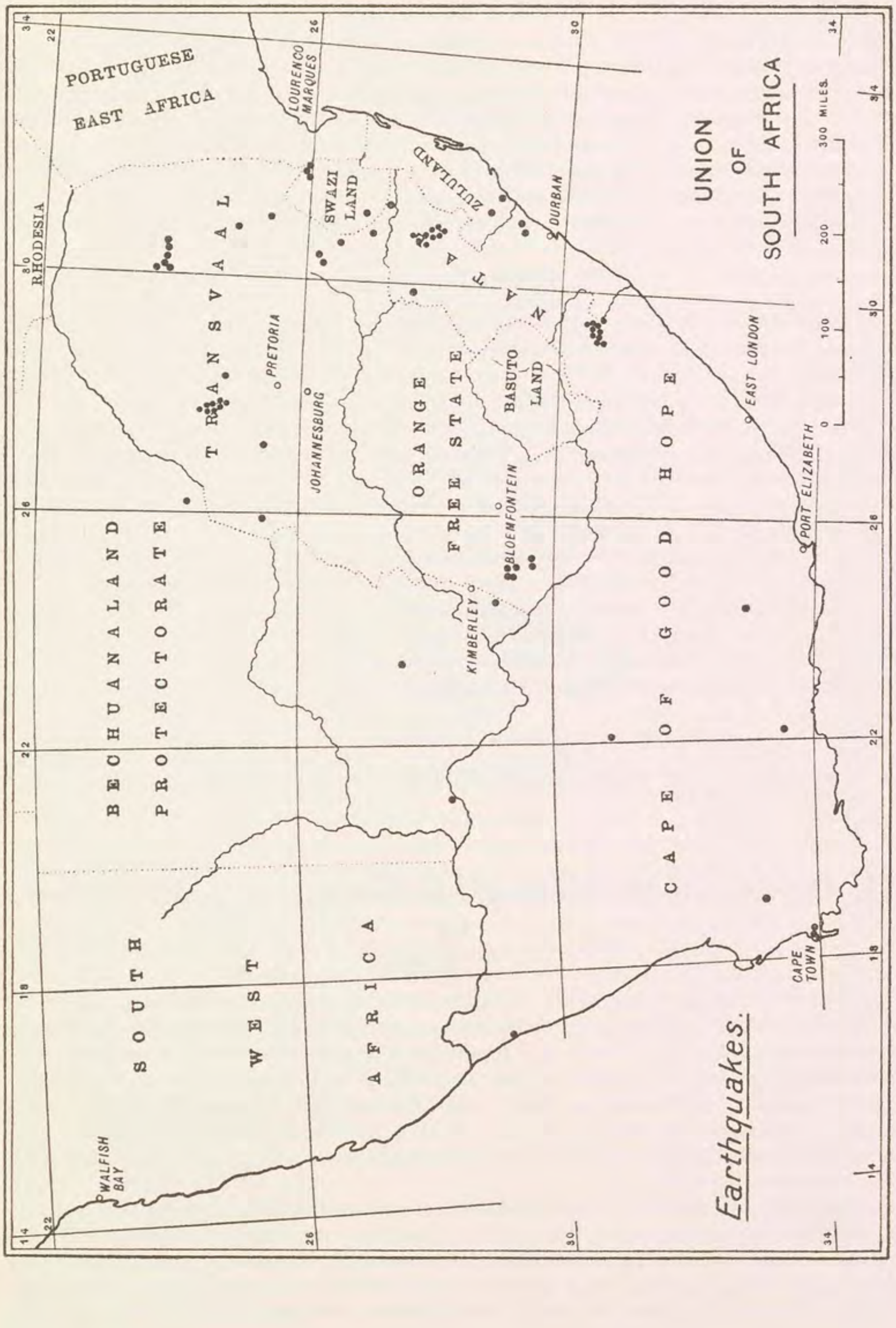


Fig. 1. Outline Map showing the distribution of Earthquake occurrences.

Transvaal traverses the escarpment by a gorge and joins the Limpopo in the Low Country. The character of the Olifants valley indicates that it is a feature of considerable antiquity, not the result of a recent capture of inland drainage by a more steeply graded river cutting back into the escarpment, though it may have had such an origin. An analogous feature in the west, where the Buffels and Green Rivers receive the drainage of part of the interior slope of Kamiesberg, is probably the result of a more recent encroachment on the catchment of the Orange River. In the south the Gamtoos and Great Fish Rivers have enlarged their catchments considerably at the expense of the southern tributaries of the Orange, and in the east the Buffalo River has done the same above Charlestown at the expense of the Vaal River.

c) Earthquakes.

The distribution (see fig. 1) of recorded shocks in the Union shows that below the eastern part of the Great Escarpment they appear to be more frequent than elsewhere, and that other areas of frequency are the western part of the Central Transvaal Bushveld, Groot Spelonken and the south-western Orange Free State. The shocks are mild, and one must remember that in a thinly populated region like Bechuanaland, the Limpopo valley, the Karroo and the north-western districts of the Cape records may be imperfect. It may be significant that the recorded quakes are numerous under the highest part of the Escarpment, where local differences in level of the present surface are great; that the central Transvaal Bushveld is a region affected by post-Karroo faults and is the site of the Pretoria Salt Pan, perhaps the latest structural feature which has come into existence within the Union; and that the south-western part of the Free State has perhaps more pipes and fissures related to those filled with kimberlite than any other region of the same size. Of the recorded earthquakes that of 1809 described by W. J. Burchell seems to have been the most severe; buildings were cracked and parts of them displaced.

References:
Burchell, W. J. "Travels in the Interior of Southern Africa." Vol. I, 1822, p. 27 and others.
Mr. H. E. Wood, M. Sc., F. R. A. S., of the Union Observatory very kindly placed his records of earthquakes at our disposal, and it was from these records that the map showing their distribution was drawn.

II. Outline of the Geological History of South Africa.

By

A. W. Rogers.

The Archaean sediments and volcanic rocks in South Africa cannot easily be divided into two large groups separated by an eparchaean break; the older Archaean, represented by Moodies, Kheis and Kraaipan series, have not been completely reconstituted, and it may well be that the highly metamorphosed rocks of much smaller extent really belong to those series, for many of these smaller bodies were clearly detached from the larger masses, in part as completely altered, in their neighbourhood. In these very ancient series volcanic rocks play an important but not a dominating part.

The Witwatersrand-Ventersdorp formations are the earliest from which much has been inferred concerning the history of sedimentation and vulcanicity in South Africa. Together these formations reach a maximum thickness of more than 35000 feet (10668 m), representing a period during which sedimentation was dominant at first over the southern Transvaal, while later on volcanic activity prevailed over an area extending at least from the Prieska district north-eastwards to Crocodile Pools. As yet these rocks have not been identified under the Nama system in the west of the Cape Province or in the eastern Transvaal. Work now being done on the Pongola beds of the eastern Transvaal at present suggests their close connection with Moodies series, not with the Witwatersrand system. The Witwatersrand-Ventersdorp beds are, there fore, apparently restricted in their distribution to the western and southern Transvaal, the northern part of the Orange Free State and the northern Cape Province. The several unconformities known within them show that the period was one of disturbances on a great scale; most striking instances are found in the Witwatersrand district itself, where there is evidence of unconformable overlap northwards of the Elsburg beds and again of the Ventersdorp beds. In Klerksdorp and the Cape Province there are considerable unconformities within the two systems. It is likely, therefore, that these formations once had a much greater extent than they have today, and that it is only where they were thicker than usual, or were protected by having been folded in synclines, that they escaped removal by denudation in pre-Nama times.

The Witwatersrand beds include some 25000 feet (7600 m) of sediments near Johannesburg; the lower half of the formation contains a very much larger proportion of shales than the upper, and each of the five major subgroups recognized in the system is reduced in thickness by more than a third in Heidelberg, though each maintains many of the characters which distinguish it on the Rand. In the Venterskroon region the formation is of about the same thickness as on the Rand, though the conglomerates are less frequent and thinner. The evidence on the Rand points to the derivation of the sediments from the north and their deposition in an extramarine area of subsidence. The extensive but thin sheet of conglomerate called the Main Reef Leader is attributed by MELLOR to a sudden flood of short duration working on material accumulated in the north, and he pictured the Upper Witwatersrand beds as a delta. The explanation may perhaps apply to the whole system, which is conspicuously free from limestone and calcareous shales. Lavas of intermediate to basic composition occur at the base of the Witwatersrand beds round the Vredefort granite; in the Jeppestown beds, where, in Heidelberg, they lie on more acid lavas and breccias; and in the Main-Bird series of the East Rand, Heidelberg and Vredefort. These lavas are greatly exceeded in importance by the later Ventersdorp lavas of acid and basic composition, with which are associated coarse conglomerates and other sediments, including limestones, in the Cape Province and the southern Transvaal. The unconformities which are the grounds for separating the Ventersdorp formation in the Cape Province into three groups, the Zoetlief, Kuip and Pniel series, are evidence of considerable earth-movements, and the thick lavas of Klipriversberg were involved in the folding which produced the east-west syncline south of the Witwatersrand and also in the overthrusting northwards near Johannesburg; these disturbances were completed before the Black Reef series was laid down in the southern Transvaal. The conspicuous unconformity within the Black Reef series at Leijfontein, on the Kaap escarpment, proves that disturbance continued during its deposition, and the volcanic rocks immediately above the main body of the Black Reef quartzites in Vryburg and Mafeking prove that a source of basic lavas, indistinguishable in character from much of the Pniel lavas, persisted in that region.

The Nama period of sedimentation has left its beds over a more extensive region in South Africa than any other except the Karroo, if the correlation of the Transvaal formation with the Malmesbury and others in the west is well founded. It commenced with arenaceous beds, the Black Reef series, which is over 2000 feet (610 m) thick on the eastern escarpment but diminishes to a few feet in the southern Transvaal and a few tens of feet in Namaqualand. In the west, generally, arkose and quartzite lie on granitic rocks which have an irregular surface, and there are places where arkose fills the spaces between great boulders of gneiss, while in Gordonia and South West Africa ancient hills of gneiss, like the Inselberge of later times, are being revealed by the removal of the local representatives (Kuibis and Zwart Modder beds) of the Black Reef series. The Campbell Rand series or Dolomite, which follows the Black Reef series, is mainly a magnesian limestone in the Transvaal and South West Africa; shales and argillaceous and arenaceous rocks play an increasingly important part in the formation as it is followed southwards, but limestones are again important in the Cango and Humansdorp. There is probably in places slight unconformity at the base of the succeeding Pretoria or Griquatown series, but the change in type of deposit, on which the separation of the series chiefly depends, from carbonates to fine-grained materials, took place gradually, for the two are interbedded. The limestones probably were of marine origin, and they perhaps record the only period of marine conditions through the interior of South Africa. Coarse sandstones reappear in the Pretoria series in the Transvaal, and the Ibiquas series of the west, perhaps the correlatives of the Pretoria Series, include coarse felspathic grits. The highly ferruginous thinly banded siliceous rocks, particularly characteristic of the Pretoria beds in Griqualand West and Bechuanaland, are most probably of non-marine origin. Beds of glacial origin have been found in the Pretoria series in Griqualand West and the Transvaal, and in each region they are followed by volcanic rocks, andesitic flows and agglomerates.

The next bedded rocks in the Transvaal are those called the Rooiberg series; the arenaecous beds in the group have a likeness to those of the Pretoria series but are more felspathic, but the Rooiberg beds are believed to lie unconformably upon the older rocks of the Transvaal System in the west central Transvaal. The most striking components of the Rooiberg series are felsitic lavas, tuffs and agglomerates, believed to be the earliest product of the long period of igneous activity which gave rise to the Bushveld igneous complex, the most important structural feature in the Transvaal. Stretching east and west for 350 miles (563 km) with a width of over 130 miles (210 km) this is a body of coarse-grained igneous rocks, granite in the centre surrounded by irregular belts of norite, gabbros and dolerite; it is covered in part by Waterberg and Karroo sediments resting unconformably on the several members of the complex, and in part by Rooiberg beds which are metamorphosed by it and evidently formed its roof in places. Professor Daly and his colleagues put forward the view that the rock magma reached the surface over wide areas through the collapsing Transvaal formation and solidified as felsitic lavas, with occasional explosive outbursts; at some depth the magma consolidated as granophyre, and beyond that as norite. The Transvaal system, some 18000 feet (5500 m) of sediments, sank in the form of a basin, elongated east and west approximately parallel in direction to the earlier Witwatersrand trend, leaving great bodies of rock detached in the invading magma. The great basin of magma filling the syncline allowed the formation of strata in which the crystals of silicates collected in various proportions by gravity as they separated from the magma. The process went on rhythmically, so that we now find hill ranges made up of repeated successions of lighter and darker rocks which, when the structure is brought out by weathering, have a distinct resemblance to a sedimentary formation when seen from a distance. Finally granite invaded the already consolidated basic rocks and the sediments lying in or on them. In addition to the main body of basic rock, large numbers of sills and dykes of closely related composition invaded all the older rocks in the Transvaal. Very similar intrusions also invaded the Waterberg strata now recognized to be younger than the

Bushveld granite, so the great period of igneous activity may have continued long after the granite had solidified and had undergone erosion.

The eruption of the Pilandsberg lavas and the soda-rich intrusions allied to them may also have been connected in origin with the complex, but the lavas were poured out after denudation had removed the upper part of the complex, possibly after the Waterberg beds had been deposited and eroded from over that area.

That the Waterberg formation itself was affected during the latest stages of the central Transvaal subsidence appears to be proved by the parallelism in outline of the Waterberg syncline in the Middelburg district and the larger trend lines of the complex and the enclosing structural basin.

In the southern Transvaal and northern Orange Free State there is an inlier of Witwatersrand, Ventersdorp, Black Reef, Dolomite and Pretoria beds surrounding a circular area of granite still partly covered unconformably by Karroo rocks. The older beds are inverted, dipping inwards towards the granite, and they are considerably altered in mineral composition, though the metamorphic zones are not concentric with the granite. Recent studies indicate that the circular infold is due primarily to centripetal pressure accentuated by uplift of the central pre-Witwatersrand granite, and that the metamorphism is due partly to the intrusion of alkali-granite of slightly later age than the Bushveld complex and partly to the dynamic effects of load and centripetal thrust. The central granite had nothing to do with the thermal metamorphism, but the tops of the alkali-granite intrusions, with attendant nepheline-syenites, are being exposed by erosion in the ring of sediments. A remarkable group of flinty crush rocks is developed in all these rocks, from the central granite to the Ventersdorp beds, and they appear to grade into enstatite-granophyre with intrusive habit, as though the violent movements which shattered the rocks led to their fusion under certain conditions. The basic intrusions of this area which belong to the Bushveld type are faulted, whereas the similar intrusions in Heidelberg and the Rand are not faulted but were guided in their distribution by the earlier faults in that region.

Up to the present time the Bushveld complex has not been connected with any great intrusions in the Cape Province or Natal. The later granites of the west and south may be of approximately the same age as the complex, but they are not comparable in kind or in the conditions of intrusion, and they are not known to have been preceded by an early volcanic phase. The Waterberg beds are known to lie in places on eroded surfaces of Bushveld granite, and therefore to be younger than it. They and their probable correlatives, the Matsap beds, are continental deposits several thousand feet thick accompanied by basic volcanic rocks in the Zoutpansberg and the Langeberg, and no younger pre-Cape sediments are known in South Africa. In the Transvaal they were deformed and subjected to northward thrusting; the fold-axes are parallel to more ancient trends in the Witwatersrand and the Limpopo valley. In Bechuanaland and the country south to beyond the Orange River the folding was carried further and the strikes are nearly north and south, parallel to the older strike of the Nama beds and the still older trend lines of the Kheis series.

With the Waterberg system we leave the unfossiliferous and presumably pre-Cambrian sediments, and as yet there is no evidence of what happened in South Africa during the first half of Palaeozoic time; we assume that it was a land area and that it was undergoing denudation, but where the products were deposited we do not know. As yet no boulders from the Cape formation have been identified in the southern Dwyka, though much of the materials in the latter came from the north, so we are not justified in supposing that the Cape sediments extended far beyond their present northern limit. The Table Mountain series is more conglomeratic in the west than elsewhere, and we may regard it as having been laid down on a sinking area fed by rivers from the west, and a glacial period was responsible for evidence suggesting that in the south-west an ice-sheet moved eastwards in places rucking up its floor of tillite and the underlying sandstone into folds with north-south axes.

In Lower Devonian times the sea gained access to the region, and its inhabitants were part of a southern fauna distinct from the contemporary fauna of Europe and North America. The deposits were laid down in shallow water, and, so far as the African region is concerned, the land lay to the north. These marine beds were followed by a great succession of non-marine beds, the Upper Bokkeveld, Witteberg, and the whole of the Karroo deposits. To the north of the area of deposition glacial conditions developed in late Carboniferous times, their oncoming being signalled in the south by the appearance of pebbles and boulders amongst the laminated muds at the top of the Lower Dwyka shales. The southern-most evidence yet found of the passage of land-ice, or possibly of a stranded berg, for the observations apply to an area only a few hundred yards in length, is at Elands Vley in 32½° S., where the underlying floor is a boulder-pavement of tillite. North of that latitude evidence of ice movements over the olde land surface is widespread and indicates a northerly source of the ice in general and an easterly source in part of Natal, where there must have been land which has disappeared. Even with the aid of WEGENER's hypothesis this distribution of the ice is difficult to understand, for at present there is no evidence of the northern complement of the Dwyka, assuming that the gathering of the ice was in high latitudes and that the ice travelled radially from it. The great thickness of the tillite in the south, over 1000 feet (305 m), is evidence of the long duration of this glacial period. In the northern half of the country the tillite varies greatly in thickness and may be absent; its former presence is in places indicated by the presence of large erratics surrounded by ordinary gravels or sandstone at the base of the Karroo sequence. The contrast between the northern and southern tillite is due to the ice passing from the land and carrying the detritus into an area of water where deposition had been in progress for a long period. Sections showing gradual change from laminated mudstone to the unlaminated gritty mudstone containing pebbles and boulders of various rocks are known in the south, and the evidence shows that from Karroo Poort in the west to the coast near the Gualana River, a distance of 406 miles, there is a conformable succession from the Cape formation up into the Karroo. The tillite is succeeded abruptly by thin bedded shales and sandstones, the Upper Dwyka Shales, which extend far to the north of the country where the Lower Dwyka Shales occur, but north of a line drawn through Kimberley to the east coast near Port Shepstone the usual types of Upper Shales are no longer found, and the unconformity of the beds resting on the tillite is marked, or the tillite may be absent. The conditions under which the Upper Shales were deposited are not yet fully understood. The most characteristic rock in them is a black shale which presents a white outcrop in dry regions and which has much carbonaceous matter and pyrites in it. In South West Africa have been found the marine fossils, an echinoid as well as *Eurydesma* and *Conularia*, which are known also on corresponding horizons in the Salt Range and Australia, while *Eurydesma* occurs in a similar position in India and Australia. In the Upper Shales the swimming reptile *Mesosaurus* is known from five or six specimens from the Kimberley region, South West Africa, Calvinia and Laingsburg, but within the Union the only other fossils are a few crustacea, a ganoid fish and a few plants. From Calvinia through the western and southern Karroo as far as Albany phosphatic nodules have been found, but they have not yielded fossils other than minute spherical bodies, the nature of which has not been determined. The positive evidence of marine conditions, then, comes from South West Africa, and the poverty of that evidence and the want of similar or better evidence throughout the known range of the shales point to the connection with the ocean having been tenuous and of short duration in the north-west, while the great region over which the shales persist in the south was not marine.

The Karroo formation, from the Ecca beds to the top of the Stormberg, some 17000 ft. (5200 m) of rock, has yielded no marine fossil, though plants and land or water-living reptiles and amphibians are preserved in it, along with a few mollusca and fish. In the Ecca and Beaufort beds local unconformities are frequent, but coarse grits and pebbles are almost entirely restricted to the regions north of the Orange River and east of the Drakensberg. The southern Orange Free State and the Cape Province appear to have been at that time the site of a delta, in which sand banks and mud islands were repeatedly formed. One of the streams contributing to the formation of the delta probably occupied the old Kaap valley and eventually filled it. HAUGHTON considers that the abundance of reptilian fossils in the Lower Beaufort beds in the south-western Karroo points to the southern origin of the thick Ecca and Lower Beaufort beds of that region. In late Karroo times a southern contribution to the deposits may have accounted for the quartzite boulders in the Indwe sandstones. In the north-eastern part of the region, where the Ecca and Beaufort beds are thinner than in the Karroo itself, the conditions brought about the formation of coal on more than one horizon, and in the south-east coal was deposited at a much later stage, shortly before the Karroo sedimentation was brought to a close by the deposition of considerable thicknesses of aeolian dust and sand, occasionally enclosing thin bands of shale in which crustaceans and insects have been found, evidently pan muds.

The greatest deposition during the long period of sedimentation lasting from Devonian or earlier times to the Triassic was probably in the south, where the Cape ranges now are, for measurements show that some 25000 feet (7600 m) of beds may have accumulated in that region. The northern land at an early date extended southwards on the east and west of the region, and presently earth movements followed which made the great southern arches and troughs in late Permian or early Triassic times. Meanwhile, north of this rising area, the higher Karroo beds (Stormberg series) were being laid down, partly at least on the land itself, and at the close of the folding, which was brought about by forces tending to move the Folded Belt northwards and, in the west, eastwards, igneous activity commenced in the then presumably lower land of the interior and floods of basalt covered large parts of the north-east and east of what is now the Cape Province, Basutoland, Orange Free State and Natal, the Central Transvaal, Rhodesia, and the north of South West Africa. Whether any of these separate volcanic regions were connected is uncertain, but during and after the deposition of more than 4000 feet (1220 m) of lavas with thin pyroclastic beds in the east, the whole South African region, with the exception of the Folded Belt, was invaded by dykes, sills and, in a few places, by great irregularly shaped bodies of basic magma. Near Algoa Bay the preservation, through late Cretaceous or early Tertiary faulting, of a strip of what may be regarded as Stormberg lavas, though unlike the northern basalts in containing analcite, and underlying ossiferous sediments, indicates that the lavas may have stretched over a very much larger region than the four main areas where they are now found. It is interesting to note that near the Algoa Bay faulted outlier, which is within the Folded Belt, no intrusive dolerites have been found, and that the beds containing fragments of basalt associated with the lavas may be true detrital rocks rather than pyroclastic tuffs. The basic intrusions are so abundant over some 220000 square miles (569766 qkm) of the interior that one can hardly be out of sight of them, and they occur over a much larger region in a less conspicuous way. They have not been seen in the Folded Belt; but outside it, in the Cape Peninsula and Pondoland, they are again found.

The outpouring of lavas raised the surface of the interior, and the injection of dolerite sheets, which form about a quarter of the thickness of the rocks above the base of the Karroo beds where they have been penetrated by deep bore-holes in the interior, no doubt accentuated the elevation. Together these areas of rising ground built up a land from which rivers probably flowed to the north and south. The southern streams may have gathered into an easterly flowing river close to the northern limit of the Folded Belt, and the northern streams in the Orange River, determined by an original westerly slope between the central Transvaal and the land stretching east to Basutoland, i. e. two regions of thick basaltic flows. Further north the streams gave rise to the Limpopo. The Lebombo monocline, bringing Karroo beds down to the Coast Belt, is of post-Karroo date, but that region is too little known yet to afford evidence for the antecedent, superimposed or consequent origin of the Limpopo valley across it. Our view supposes that the southern streams fed a river flowing eastwards to a Jurassic sea of which no trace remains in South Africa.

The Neocomian sea has left its inshore deposits near Algoa Bay and Knysna, and contemporaneous terrestrial deposits, found between and south of the Cape Ranges, indicate that the great synclines there were perhaps completely filled by them, so that the flood plain of the hypothetical easterly river beyond the ranges eventually merged in the terrestrial Uitenhage beds laid down between and over parts of the Cape Ranges. At some post-Neocomian date faulting occurred within the Folded Belt, causing in time downthrows of some thousands of feet on the southern flanks of the Zwartbergen, Langebergen and Zuurberg, and giving rise to new longitudinal troughs situated on the ancient buried synclines. The streams south of the main watershed were rejuvenated about that time and deepened their valleys across the buried Cape Ranges. The general south-easterly trend of these rivers was probably due to a tilt in that direction given to the land made, on the ocean side, of terrestrial and perhaps estuarine deposits of Neocomian age. The long east-west faults were accompanied by cross faults, giving rise to many east-west elongated troughs. The date of this faulting lay mainly between the Neocomian and Upper Albian, for the Pondoland and Natal marine beds of Senonian and Upper Albian age are not affected by the faults, while the Embotyi beds of Neocomian date are faulted in a way similar to beds of that age further west. Possibly the uplift which increased the down cutting powers of the southern rivers was associated with the faulting, and the valleys were maintained during the faulting; over the Cape Ranges the rivers were superimposed and were so well established that the longitudinal faulting did not divert the main rivers. Though longitudinal valleys in comparatively soft rocks are found throughout the Folded Belt, they are occupied by tributaries of the transverse rivers which keep their courses across one, two or three ranges of mountains.

It was probably during the early stages of the development of the rivers on the land formed in late Triassic and Jurassic times that the first traces of the Great Escarpment appeared, and that feature became more pronounced as elevation progressed and denudation laid bare the diverse hard strata which are found capping almost every part of it.

In the interior there are the remains of an old peneplain at about 4000 feet (1220 m) above the sea in the Vaal and Orange catchments, and below the escarpment there are fringes and outliers of peneplains up to 1200 feet (366 m) above the river beds in their neighbourhood. These peneplains have not been dated with any surety, for the higher gravels have not yet yielded fossils, but they point to general uplifts over the whole of South Africa occurring down to recent times. The ancient surface of Bushmanland, at about 3000 feet (900 m) above the sea, on which Dinosaur bones were found and which is now buried under locally derived grit, may be the western part of the old land-surface represented further east by the gravels lying at 4000 feet (1220 m) and more above the sea.

At some probably post-Neocomian date there took place intrusions and eruptions of a basic magma which produced the dykes and pipes filled with various basic and ultrabasic rocks, lamprophyres, melilite-basalt, the peridotite called kimberlite and kimberlite-breccia in which diamond is occasionally found. Their distribution in space does not appear to be correlated with any structural feature exposed at the surface. The southernmost pipe known in the country, the one filled with melilite-basalt at Spiegel River, was post-Neocomian, and the whole group may have been produced during the uplift of post-Neocomian date.

In the Limpopo valley, Karroo beds overlain unconformably by limburgite and nepheline-basalts surround the eastern end of Zoutpansberg; the Karroo beds and the volcanic rocks are thrown down along faults with east-nort-east trends, and probably the eastern part of Zoutpansberg is outlined by faults of the same date. There is no evidence of the age of the faults, except that they are obviously post-Karroo. The Pafuri River traverses Zoutpansberg in a deep valley obliquely to the strike, and it was probably superimposed on the Waterberg beds, having its origin on the surface of Karroo beds which almost certainly covered the eastern Zoutpansberg. The association of soda-rich igneous rocks with the post-Karroo faults in the Limpopo valley recalls the great East African faults and volcanic rocks, which, in Portuguese East Africa, have been dated at various times ranging from Lower Cretaceous to post-Miocene.

The Pretoria Salt Pan, a volcanic pit surrounded by a ring-fault, belongs to a much later period than the kimberlite pipes. The Karroo beds had been almost completely removed from the spot by denudation at the time when a dome of granite was raised above the position eventually occupied by the explosion channel, and the granite breccia on the inner side of the ring-fault has been shown to be a product of the outburst, large masses of similar breccia being still preserved on the surface of the granite wall of the caldera. No fragment of basalt or other volcanic rock has been found in the Salt Pan, and its position has not been connected with any structural peculiarity in the neighbourhood. P. A. Wagner suggested that it may be the southernmost of the East African volcanoes.

The remarkably even South African coast line has not received adequate explanation. It has often been held to indicate that faulting was the immediate cause, but faults on the land parallel to the assumed faults are extremely few and are only known in the east; the structure of the country, in fact, lends very little support to the hypothesis, which, however, at present seems to be the most likely explanation. Penck's hypothesis that the coast is a contour on a flexed plain, local contradictory evidence of subsidence and uplift being due to the position of the hingeline, below and above sea level at the spots, raises difficult questions concerning the straight coasts backed by cliffs and low shores in the same region, as in Namaqualand, and about the absence of greater bays of erosion than we actually find.

That the climate of most of the interior has been semi-arid since late Cretaceous or early Tertiary times is indicated by the surface contours and deposits of Bushmanland and the Kalahari, by the presence of "island mountains", and by the characters of the rivers and valleys, though their high grades are primarily evidence of long continued uplift.

III. Stratigraphy and Igneous Rocks.

1. The Swaziland System.

By

A. W. Rogers and A. L. Hall.

In the distribution of the Swaziland System it is convenient to recognise the following three principal areas: A. The Eastern area, covering the majority of occurrences in the Transvaal, Swaziland, Natal and Zululand; B. The Northern area, covering the system as developed in the Kenhardt and Mafeking districts of the Cape Province, and in the Western Transvaal; C. The Western Area, i. e. Namaqualand (Fig. 2).

The term Swaziland System, as now understood, is more or less equivalent to Schenk's Swazi-Schichten[1]; to this system are assigned those formations which can be shown, or are believed, to be older than the Witwatersrand System. The criteria for establishing this relationship are still somewhat uncertain, since in nearly every case outcrops of the Swaziland System are surrounded on all sides by granite, so one has to rely — in part — on similarity in lithological characters. The fact that the Witwatersrand System has been conclusively shown to be younger than the so-called Older Granite, whereas in most cases the granite surrounding areas of Swaziland System is intrusive in the latter, furnishes a further stratigraphical limitation depending upon the intrusive or non-intrusive relationship to the so-called "Older" Granite. The latter criterion is not satisfactory, since it supposes the possibility of establishing a definite age for a granitic formation sometimes extending for several hundred miles (e.g. between the Murchison Range in the north-eastern and Barberton in the Eastern Transvaal).

More or less profound alteration, due both to dynamic forces and to the influence of intrusion, as well as folding and faulting, or intimate association with contemporaneous volcanic or sheared basic rocks, is characteristic for most outcrops of this system. Quartzites, sheared quartzites, slates, phyllites, sericite-schists, banded ironstones, jaspery rocks, conglomerates, talcose schists, chlorite-schists, hornblende-schists, amphibolites, basic amygdaloidal rocks, granulites and occasional pyroclastic rocks are common lithological types.

A. The Eastern Area.

By

A. L. Hall.

Rocks of the Swaziland System falling into this area occur in several detached masses, completely enclosed by the Older Granite in some cases, but in others (Murchison Range) passing unconformably under the base of the Transvaal System along the Drakensberg.

These form somewhat narrow strips of country commonly elongated from east-north-east to west-south-west, an alignment, which plays the role of a major tectonic direction of regional character. The principal developments are:—Barberton (including Swaziland), the Murchison Range, Mount Maré, and several minor masses north of Pietersburg, the South-Eastern Transvaal, and Natal, including Zululand.

[1] Die geologische Entwicklung Südafrikas. Petermanns Mitt. 34, 1888, pp. 225—232.

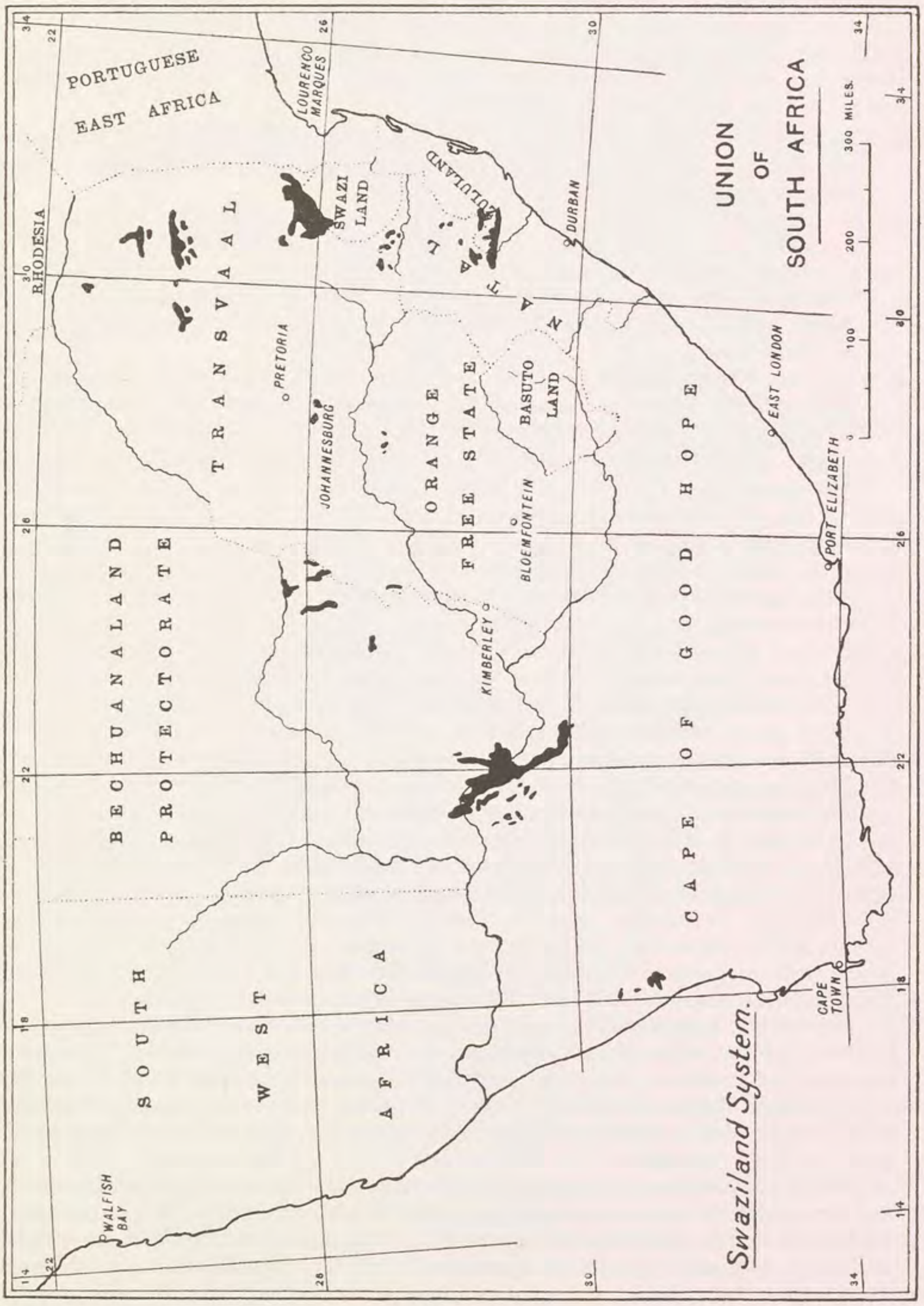


Fig. 2. Outline Map showing the distribution of the Swaziland System.

a) Barberton District, including Swaziland.

The most extensive and best known development of the Swaziland System lies in the Eastern Transvaal and covers the whole of the so-called "Barberton Mountain Land" and the Jamestown belt of high ground. Here the Swaziland System is built up of three groups:—

1. Moodies Series—the sedimentary division, composed essentially of quartzites and slates; these are the oldest rocks in the district; the thickness of this series is approximately 25000 feet (7600 m).
2. Onverwacht Volcanic Series—a group of basic amygdaloidal rocks (in part sheared), intimately associated with basic schists, talc-carbonate rocks, quartz-porphyries, nodular greenstones etc. and including banded ferruginous chert; this assembly probably represents a contemporaneous volcanic phase in Moodies Series and is characteristically developed in the Komati River Valley south of Barberton.
3. The Jamestown Series—composed of talcose, chloritic, hornblendic and other basic schists, serpentine, massive talcose rocks, together with thin bands or slaty quartzites and quartzitic slates; this series is round 8000 feet (2400 m) thick. Its distribution is normally between the granite and Moodies Series.

The surrounding Older Granite is intrusive in all the above groups. In the first place it cuts off, transgresses and invades the sediments. In the Hectorspruit area it cuts off almost the entire succession, while south of Kaapmuiden it transgresses across the strike as far as the Lily Line and thus forms a kind of regional apophysis —results analogous to the powerful intrusive transgression of the Bushveld Complex at Potgietersrust. In the second place granitic veins occur all round the Mountain Land; here also belong the sheared quartz porphyries (sericite schists) of Piggs Peak, Louws Creak, etc., as well as the quartz porphyry offshoots intrusive in the Onverwacht Volcanic Series in the Komati River, or that in Barberton itself. In the third place, endomorphic variations in the granite are seen in finer grained marginal changes (Hectorspruit) and in gneissic habit without mechanical deformation, the gneissic structure striking with the sediments. In the fourth place the marginal portions of the Mountain Land form a belt of contact altered rocks. This metamorphism is more striking in Moodies Series than in the other groups. Andalusite-slate with or without ottrelite is the commonest altered rock, followed by chiastolite-slate, biotite-hornfels, and altered quartzites; the list of contact minerals is as follows: andalusite, ottrelite, biotite, chiastolite, garnet, sillimanite, tourmaline, zoisite, staurolite, cordierite, and corundum. The schists of the Jamestown Series are locally rich in tourmaline (Darkton in Swaziland), while in the Onverwacht Volcanic Series there is wide recrystallision of the amygdaloidal lavas.

In the acid intrusives of granitic origin, also in both the sedimentary beds and the basic schists, tourmaline is common. The width of the contact belt, in so far as the above minerals are concerned, rarely exceeds three miles, and shows in one area a progressive increase in intensity on approaching the granite margin. Siliceous slates, sandy slates, impure shales, banded quartzite, and talcose schists are the principal rocks affected.

The metamorphism is essentially thermal, but accompanied by pressure effects, and its agent is the intrusive granite, and not the basic formations of the Jamestown Series; the latter possibility is negatived: by the nature of the alteration—highly typical of a granitic contact (e. g. chiastolite slate); by the intensity and great distribution of the altered rocks, out of all proportion to the width of the Jamestown Series; by the presence of the same altered rocks, where the basic schists are not represented at all (e. g. Hectorspruit, Wyldsdale); and lastly, by the increase of intensity as one approaches the granite junction, i. e. round the Consort Mine. Nevertheless, the occurrence of pyroxene and hornblende in some of the hornfelses, e. g. round Joe's Luck, indicates that the intrusion of the Jamestown Series has had its own effect on the sedimentary rocks, by a certain amount of transference of igneous material.

The following table shows the principal features of the Barberton Contact Belt in comparison with the Aureole of the Bushveld Igneous Complex and brings out the essentially thermal character of both, modified by a somewhat stronger pressure component in the former area:—

	Bushveld Aureole	Barberton District.
Contact minerals in order of abundance	Biotite, cordierite, chiastolite, staurolite, andalusite, garnet, muscovite, sillimanite, ottrelite, corundum, tourmaline.	Andalusite, ottrelite, biotite, chiastolite, garnet, sillimanite, tourmaline, zoisite, staurolite, cordierite, corundum
Biotite	Very abundant	Fairly common
Cordierite	Very abundant	Rare
Chiastolite	Very abundant	Restricted
Ottrelite	Rare	Abundant
Garnet	Occasionally	Fairly common
Tourmaline	Great vertical range; universal in minute quantities	Small vertical range; abundant at isolated localities
Hornfels (Groothoek type)	Very abundant	Rare
Chiastolite-slate (Longsight type)	Very abundant	Restricted
Andalusite-slate (Longsight type)	Rare	Abundant
Ottrelite-slate (Longsight type)	Rare	Abundant
Malips River type	Rare, except in north-eastern corner	Fairly common
Pure shales	Very common	Rare
Impure shales	Rare	Very common
Sieve and pavement structures	Common	Common
Width of aureole	Up to 10 miles (16 km)	Up to 3 miles (4.8 km)
Recrystallisation	Common	Common

The intrusion of the granite was accompanied by great pressure of a mountain-building character, and its effects are traceable over greater distances across the strike, in the widespread distribution of cataclastic structures in the more resistant rocks—no longer accompanied by contact minerals. Hence there is a structural and a mineralogical aureole, the former not only covering the latter, but extending probably over the entire Mountain Land. This result has an important bearing on the economic deposits.

1. The Moodies Series.

The distribution of Moodies Series (named after the locality of Moodies Hills west of Barberton) coincides with the Barberton Mountain Land, a tract of hilly country, some 70 miles long and up to about 18 miles wide, extending from Salisbury Kop near Hectorspruit station on the Eastern Line along a general south-westerly direction to near Hlom-Hlom on the Komati River, and also southwards to Forbes Reef in Swaziland. These three points:—Hlom-Hlom, Forbes Reef, and Salisbury Kop, form a narrow triangle, elongated towards Hectorspruit and having the line joining Hlom-Hlom with Forbes Reef for its base. Near the apex the belt of hills narrows down, and is cut off both topographically and geologically by a broad wedge-shaped prolongation of intrusive Older Granite. A little east of Louws Creek the belt widens until near the Barberton-Piggs Peak section the major trend lines divide into two sets; the main branch continues in the original south-westerly direction towards the Komati River, while a second branch gradually assumes separate identity southwards across the Komati River to Forbes Reef in Swaziland.

The Barberton Mountain Land is surrounded on all sides by intrusive granite and is built up of a conformable and non-fossiliferous succession of quartzite, with or without conglomerates, slaty quartzite, quartzitic or siliceous slates, sandy shales, greywackes, mudstones, variegated so called "ribbon" shales, bars of chert, jaspery rocks, banded ferruginous siliceous beds (banded ironstone, "bacon" or "calico" rock) and other phases of semi-argillaceous, semi-arenaceous, or siliceous nature. Broadly speaking, these are distributed in such a manner that the prominent ridges mark the quartzites and other hard beds, while the intervening valleys are usually determined by shaly and similar soft rocks. The former rise into several powerful peaks well over 5000 feet (1520 m) above sea-level, the highest point being Emlembe Mountain with an altitude of approximately 6030 feet (1838 m).

The structure of the Barberton Mountain Land (Moodies Series) is determined by the prevalent steep south-easterly and southerly dip combined with powerful tectonic disturbances due to the intrusion of the granite. The dip ranges from 30° to 90° and is often nearer 60°; along the northern contact with the granite the beds may be overturned through about 10° and dip northwards. Close to Barberton on the north side is a well defined band of conglomerate, but as it does not occupy a definitely basal position, there is some doubt whether the sequence of beds from north-west to south-east corresponds to a true upward succession.

The effects of powerful pressure—belonging to a pre-Transvaal system of earth movements—are seen in faults cutting obliquely across the strike and in folds—both of the strike fold (Sheba Hills) and dip fold (Ingwenya Range) type—which lead to single and multiple duplications, with locally a much increased apparent thickness of the series ("tectonic thickening" in the Sheba Hills area). Lithologically these pressure effects are revealed by widespread cataclastic phenomena—i. e. strain shadows, mortar structures, augen-structures, recrystallisation etc. Tectonically the following are the most important sections of the Mountain Land:—The Sheba Hills, the Louws Creek area, the Ingwenya-Emlembe Ranges, and the Kamhlubana Kop—Ufafa—Kobolondo Area.

The **Sheba Hills** lie along the northern edge of the Mountain Land and present a remarkable case of intense isoclinal strike folding (Fig. 3), well brought out by hard quartzites and chert bands, which are several times repeated and through their resistant nature reveal this folding in a series of converging ridges. Between Mysidora Creek in the west and Louws Creek on the east there are at least 10 hard bands developed through folding from only four separate horizons; these are:—the Woodstock Bar, then the Baviaanskop Bar (occurring five times), then the Sheba Bar occurring three times) and lastly the Ulundi Bar. The last two are banded cherts or banded ferruginous rocks, the Baviaanskop Bar is a true quartzite, and the Woodstock Bar is a very hard schistose siliceous rock with chloritic partings. The intense folding (Fig. 3) can be easily followed by the distribution of the Bavianskop Bar, a hard resistant band of quartzite some 90 feet thick, which several times terminates and turns backwards from a vortex point (Fig. 3). At the latter the dip slopes show a curvature, there are no fault displacements, the quartzite does not extend further along its original strike, neither do underground mine workings reveal any such continuation.

The cause of this powerful strike folding is the intrusion with great tectonic effects of the De Kaap Granite and that of the Crocodile Poort Ranges. In consequence the Sheba Hills section of the Mountain Land suffered intense pressure, a portion of Moodies Series being compressed from two sides and thrown in great strike folds. This most probably accounts for its much greater apparent thickness east of Barberton.

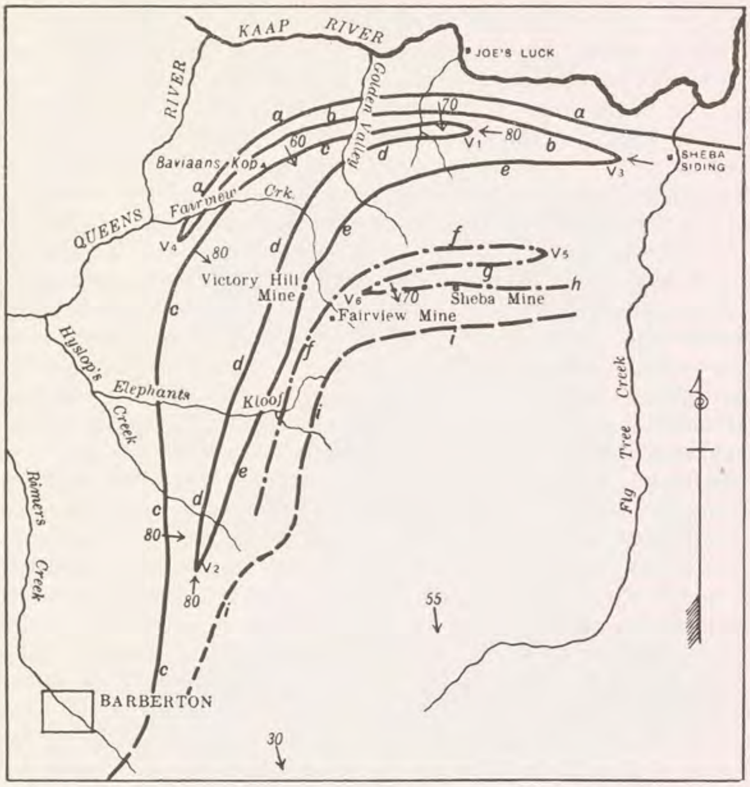


Fig. 3. Sketch Plan to illustrate the folding in the Sheba Hills, Barberton District, Transvaal Province.

a. Clutha Bar. b. Joe's Luck Bar. c. Baviaanskop Bar. d. Intermediate Bar. e. Victory Hill Bar	Baviaanskop Quartzite.	f. Sheba Bar. g. Southern Gross Bar. h. Zwartkopje Bar. i. Ulundi Bar.	Sheba Bar.

V 1 to V 6 — Vortex points of te strike folds.
Scale: 1 inch = 2.35 miles (3.76 km).

In the **Louws Creek Area** round the Three Sisters Kopjes the complex structure of Moodies Series is seen in the sudden termination of the most westerly and much more prominent (3820 feet [1164 m] above sea level) of the above three peaks. The latter lies along an irregular high ridge which extends as a double feature for at least 9 miles (14,5 km) to the east and consists of quartzite and conglomerates. The floor of the deep Revolver Creek valley separating the Three Sisters Belt from the Lily Line on the south, also due to quartzites, probably more or less coincides with a powerful fault which cuts off the latter ridge and duplicates it into the Three Sisters ridge, after the latter had been thrown into a compressed and nearly isoclinal syncline; this terminates towards the west against the oblique fault and is connected by an anticlinal air saddle with the normally disposed Lily Line. (Fig 4a and b).

From Louws Creek eastwards the synclinal arrangement of the Three Sisters Ridge is continued almost as far as the Hectorspruit granite mass, the southern line being continuous with the high ridge that includes the Ironstone Kop south of Malelane, until the structure ends against the intrusive transgression of the granite.

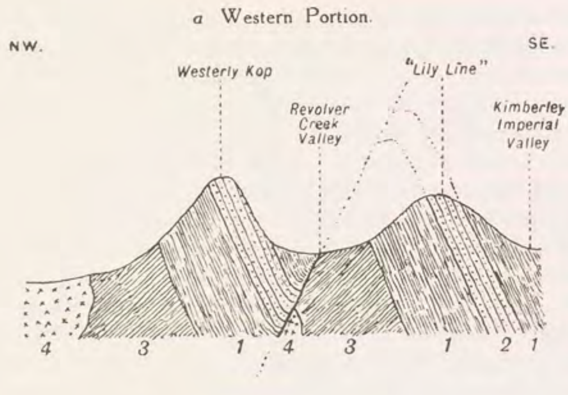
On the south side of the Mountain Land within the **Emlembe — Ingwenya Ranges** at the Ingwenya Trigonometrical beacon overlooking Forbes Reef in Swaziland, the powerful Ingwenya Quartzite dips normally to the east, but has been folded over, the whole area showing much disturbance so as to form anticlinal structures with quaquaversal dips. Near Forbes Reef this quartzite bifurcates through dip folding and continues as two bands, separated by the Long Valley, beginning as a narrow valley rapidly deepening and opening out towards the north. The eastern quartzite band includes the prominent conical peak of the Umkomogaas — 5480 feet (1670 m) above sea level — and continues northwards across the Komati River into the Kobolondo Range. The western limb of the quartzite forms the Ingwenya Range proper, also crosses the Komati River and passes northwards as a very powerful high ridge defining the eastern slopes of the Umsoli and Josefsdal valleys, beyond which it is cut off by a fault and displaced towards the west (Fig. 5). Still further north it culminates in the Emlembe Mountain—the highest point in the whole Mountain Land (6030 feet [1838 m] above sea level), thence continuing (after displacement) as an extensive ridge of quartzite, marked by the Bothlwane, Ufafa, Makonjwa and Kamhlabana Peaks. The above structure is based on a sharp double fold, consisting of a westerly anticline followed by an easterly syncline, both powerfully and isoclinally compressed. This folding begins at the Ingwenya Trigonometrical beacon, but does not yet involve the great thickness of underlying banded ironstones, which begin to be folded into the synclinal area in proportion as the Long Valley becomes more pronounced. The great development of banded ironstones west of Pigg's Peak is probably the same band, which underlies the Ingwenya quartzite and crosses the Komati River in a conspicuous outcrop at the entrance to its lower port; it is also found at The Heights, where it suffers the same displacement as the overlying Ingwenya quartzite in its Emlembe position, and may be correlated with similar rocks seen on the Barberton-Piggs Peak path between the Staircase and Kamhlubana quartzites. This folding accounts for the enormous apparent thickness of Moodies Series.

In the **Kamhlubana Kop — Ufafa — Kobolondo Area** repeated foldings give rise to a series of anticlines and synclines between the Inyoka Valley and Ufafa Kop, and to the pronounced anticlinal structures of Kamhlubana, which affect the entire width of the quartzite, here not less than 800 feet (245 m) thick. Similar effects can be traced in the Kobolondo area (Fig. 6, see plate II).

Lithologically the Moodies Series falls into two groups, an arenaceous phase consisting of quartzites with conglomerate bands, and an argillaceous phase of impure shales, slates and similar varieties. One also finds hard banded ferruginous slaty quartzites ("banded ironstones" or "calico rock") as well as cherts, both with highly variable iron content and locally jaspery, and there are so-called ferruginous "ribbon" shales; the former may be classed with the first, and the latter with the second group; there are also some intermediate varieties.

In the **Quartzite Group** the leading horizons from north to south are as follows:—

The Baviaanskop Quartzite, together with its four duplications forms the skeleton of the Sheba Hills and varies from 80 to 200 feet (24 to 60 m) in thickness. It is a somewhat thinly bedded dark grayish rock composed of larger grains of quartz, sometimes interlocking or set in a completely recrystallised mosaic of silica, showing mortar structure; occasionally it includes pebbly washes. The Ivy or Woodbine Quartzite is very prominent in the scenery west of Barberton, where it determines the highly sculptured portion of Moodies Hills and is liable to rapid changes in facies, leading to forms intermediate between shales and quartzites. It is at least several hundred feet thick and on the Ivy footpath shows a band of pebbly washes passing into a conglomerate about 15 feet thick. The Alpine quartzite



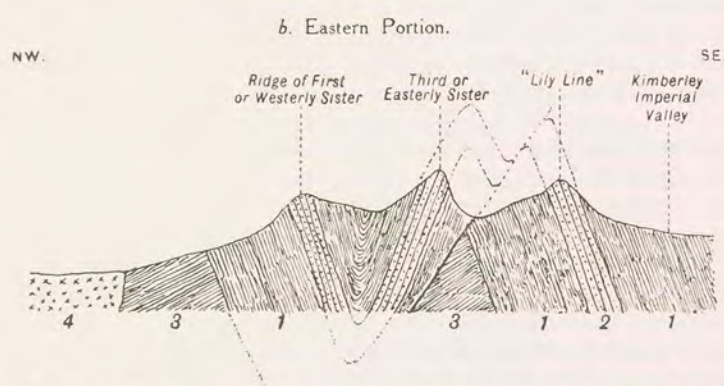


Fig. 4a and b. Diagrammatic Sections across the three Sisters Range and the "Lily Line" east of Louws Creek, Barberton District, Transvaal Province.

1. Slates.
2. Quartzites and conglomerates.
3. Jamestown Series.
4. Granite.

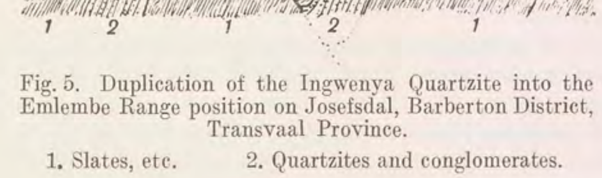


Fig. 5. Duplication of the Ingwenya Quartzite into the Emlembe Range position on Josefsdal, Barberton District, Transvaal Province.

1. Slates, etc. 2. Quartzites and conglomerates.

is sensibly vertical and at the Alpine Mine in Moodies Hills forms very smooth precipitous walls often very regular for greater distances. This rock is very evenly fine-grained and sometimes coated on its weathered surfaces with a delicate black shining film of shaly matter; its thin section shows a fair amount of calcareous matrix. Near the Alpine Mine this band is not less than 500 feet (152 m) thick. The Saddleback quartzite forms the highest ridge immediately south of Barberton and is noteworthy for its persistent conglomerates or coarse pebbly washes. At the summit of the Saddleback are two bands of conglomerates, each some 20 feet (6.1 m), full of smooth well-rounded pebbles of chert, fine-grained white quartzite, black quartz, banded siliceous or cherty material, and of calico rock; these rarely exceed 2×1 inches (5×2.5 cm) in size. Following southwards comes the Staircase Quartzite, and then Ingwenya (= Kamhlubana) Quartzite, which extends from Forbes Reef in Swaziland to Kamhlubana Kop and is often dark gray or almost black and has conglomerates strongly developed. At the Ingwenya beacon the rock is fine-grained, hard and brittle and almost black with many minute and nearly black crystals of quartz, and a little pyrites. The beds are rarely free from pebbles, either isolated or concentrated into washes, which pass locally into sheared conglomerates with at times more pebbles than matrix. The latter are up to 4 inches (10 cm) long and due to fine grained white sugary quartz, glassy quartz, black chert and banded ironstone. True conglomerates rarely exceed 6 feet (2 m) in thickness. On the summit of Emlembe Mountain these conglomerates are also built up of red banded jaspery rocks, often seen as rectangular fragments up to 3×2 inches (7.6×5.1 cm). The same quartzite is very marked at Kamhlubana Kop where it also carries well defined conglomerates. At the Ufafa Peak the Ingwenya quartzite is at least 800 feet (244 m) thick. The Three Sisters quartzite east of Louws Creek is rich in conglomerates, forming bands 60 to 80 feet (18 to 24 m) across; they are more or less highly sheared. The Lily Line is a very sharply defined ridge persisting from Joe's Luck eastwards past the south side of Louws Creek, and consists of two parallel bands of ferruginous quartzites, separated by siliceous slates.

All the quartzites have suffered recrystallisation, show mortar structure and other effects of mechanical deformation, and are locally characterised by ottrelite.

Horizons showing much cherty and ferruginous material include bands closely associated with goldbearing deposits. Here belong:—

The Sheba Bar; this is of great importance in the Sheba Hills area, where its duplications are known as the Zwartkopje and Southern Cross bars (Fig. 3). It is from 15 to 50 feet (4.5 to 15.2 m) thick and usually made up of a whitish banded rock, consisting of layers of compact or very finely granular cherty matter, interleaved with delicate partings of dark more or less ferruginous chert. In the Intombi Mine its Southern Cross Bar forms a brittle and highly siliceous rock, made up of much compact black cherty matter and associated with bright green siliceous portions; traversing it in all directions are many delicate veins of dark gray translucent lustrous quartz, the whole, being now and then sprinkled with pyrites. The Jasper Bar on Moodies Hills is conspicuous close to the Alpine Mine and though only 3 feet (0.91 m) thick, is very characteristic through its red jaspery ferruginous chert. The Oratava Bar is the most prominent of three further cherty horizons situated south of the Sheba Bar east of Barberton and is made up of whitish chert with vivid green chloritic partings.

These "bars" are probably of sedimentary origin and represent an extreme type of sandy ferruginous ribbon shale, modified through secondary silicification.

The **Argillaceous Group** of Moodies Series consists of softer thinly bedded, more or less well laminated rocks, usually forming the valleys or lower ground between the ridges. Here belong various slates, shales, mudstones, flagstones, siliceous slates, sandy shales, greywackes, etc. mostly marked by negative characters, and often showing sandy admixtures. The colours vary between dirty yellowish gray, pale brown and dark bluish gray tones.

Banded or Ribbon Shales, characterised by well marked ferruginous content, are abundant, specially east of the Fig Tree Creek valley, where they form a considerable succession, e. g. between the Maid of the Mist gold mine and Louws Creek, or near the head of Revolver Creek valley. Such rocks consist of very regular alternating bands of light coloured sandy shale and dark coloured, often chocolate coloured or reddish, ferruginous sandy matter or chert (locally known as "Calico Rock"). The iron content varies within wide limits, some extreme types approaching an iron ore, e. g. Ironstone Kop south of Malelane. The Ulundi Bar is a conspicuous example of a banded ironstone in the Sheba Hills area, and west of Barberton a similar horizon (with contorted layers) occurs at the Montrose gold mine. A remarkable series of hard banded ironstones underlies the Ingwenya quartzite and is not less than 400 feet (122 m) thick; where it crosses the Komati River at the entrance to its lower port, the intense folding and complex minor contortion forms a striking example of the intense pressure to which Moodies Sries was subjected.

More or less all round the Mountain Land the series has been strongly metamorphosed by the intrusion of Older Granite (see below).

Igneous Rocks are not common in Moodies Series and are represented by a few basic sheets and dykes in the northern margin of the Mountain Land. These are of post-Pretoria Series and pre-Karroo age and belong to dyke systems of the De Kaap Valley (see below under Older Granite).

Owing to heavy folding and faulting, an accurate estimate of the thickness is impossible; thus the complex structure of the Sheba Hills (Fig. 3) requires a width of at least 4 miles (6.44 km) of country to be eliminated from the apparent thickness, and similarly on the south side at least 7 miles (11.26 km) of country represent repetitions. Allowing for these factors, the approximate values are indicated for different parts of the series:—

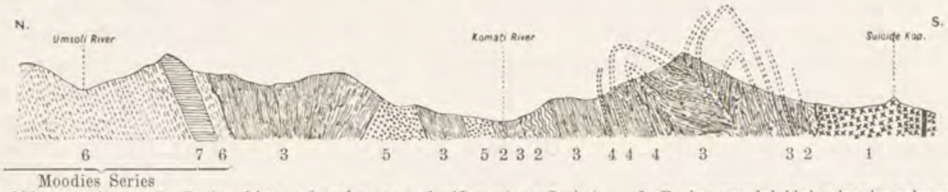
Big Buffalo	21000 feet	(6400 m)
Kamhlubana Kop—Three Sisters Line.	31000 ,,	(9449 m)
Sheba Hills area	33300 ,,	(10150 m)
Barberton—Emlembe Line	32500 ,,	(9906 m)
Schoongezicht, west of Barberton	11800 ,,	(3597 m)

Fig. 7. Section across portion of the Onverwacht Volcanic Series from the Komati River to Onverwacht, Barberton District, Transvaal Province.

1, 4, 6, 8, 10, 12, 14, 16, 18. Quarz Porphyries.
2, 5, 15, 17, 19. Altered "Nodular" basic lavas.
3, 7, 9. Serpentine. 11. Altered Dolerite 13. Gabbro.

2. The Onverwacht Volcanic Series.

The Onverwacht Volcanic Series is named after the type locality Onverwacht Nr. 72 in the valley of the Komati River and occupies a large area on the Mountain Land within the Komati River basin. The section across Onverwacht (Fig. 7) shows a succession of basic amygdaloidal lavas (probably metamorphosed) associated with intrusive light coloured quartz porphyries, doleritic rocks, gabbroid varieties and others. Elsewhere the volcanic phases predominate and give rise to a succession of irregular hills distributed for the most part along the left bank of the Komati River. Volcanic activity was, however, intermittent, so as to allow for short periods of sedimentation (banded ferruginous cherts), as shown in Fig. 8; these cherty bands are up to 300 feet (91 m) thick.



1. Older granite. 2. Basic schists and carbonate rocks (Jamestown Series). 3. Basic amygdaloidal volcanic rocks, etc. (Onverwacht Volcanic Series). 4. Banded ferruginous chert, etc. 5. Quartz porphyries (granitic origin?). 6. Slates, etc. 7. Quartzite (Staircase quartzite?). — Length of Section approximately 14 miles.

Fig. 8. Diagrammatic Section from Suicide Kop to the Umsoli River, Barberton District, Transvaal Province.

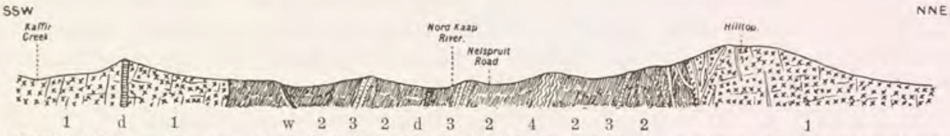
The prevalent rock is a massive fine grained to compact type which probably originated as an amygdaloidal basic lava, now altered, and in part sheared. In larger outcrops broad massive zones up to 4 feet (1.2 m) wide alternate with narrow schistose zones and show elongated vesicular areas sometimes arranged in linear fashion. The amygdules are mostly filled with chlorite and quartz, and lie in an essentially hornblendic groundmass; where they become more numerous, larger, and are completely recrystallised, they give rise to knob like excrescences from which the rocks acquire more or less pitted weathered surfaces.

3. The Jamestown Series.

The Jamestown Series forms a long narrow belt of hilly country reaching from the northern edge of Moodies Series near Nordkaap north-westwards to the Drakensberg, where it passes under the escarpment of the Black Reef Series to reappear from below the quartzites of the Kaapsche Hoop Plateau along the floor and lower slopes of the Elands and Crocodile River valleys round Alkmaar Station; this main belt is from one to four miles wide and about 20 miles long. Similar rocks extend from Barberton westwards along the Pioneer Creek valley and the south-western edge of the Nels Hoogte Plateau. The Jamestown Series is also strongly developed between Kaapmuiden and Salisbury Kop near Hectorspruit, where it forms a broad band of massive basic rocks rich in magnesia (serpentines, talc rocks etc.). On the Swaziland side a band of basic schists intervenes between the granite and the margin of Moodies Series. This irregular distribution is in part due to the intrusive invasion of the granite which transgresses both the Jamestown and Moodies Series in the Hectorspruit area, cutting also into the Jamestown Series as a conspicuous easterly projection south of Kaapmuiden. It is probably also in part due to the intrusion of the granite now filling the De Kaap valley, where the normal composition of the intrusive rock has been modified through the assimilation of the Series, with consequent development of a less basic rock—the De Kaap valley type of granite (see below). It thus appears that the series had a wider distribution, the present outcrop representing the remnant of an originally more extensive development of the Jamestown Series.

The planes of schistosity are often vertical, but may also be inclined at a high angle to the south or south-west in the Noordkaap-Drakensberg belt, while round the Mountain Land the strike and dip are conformable with Moodies Series. Between Eureka and Caledonian Sidings the strike of the Jamestown Series changes from south-east to south (Caledonian area) or to the east (Eureka) until it agrees with that of the sediments on the south. Here the series shows broad subparallel bands of massive magnesian rocks (serpentine etc.) probably depending upon slight variations in original composition. Round Noordkaap the general effects recall the pseudostratification in the basic margin of the Bushveld Igneous Complex. The intrusive relationship between the Jamestown Series and the adjoining granite is shown by granitic veins (Hilltop) cutting into the margin of the schists and by the metamorphism of the latter.

Lithologically the main belt from Noordkaap to the Drakensberg includes the following major groups (Fig. 9):—1. Soft basic schists; 2. Massive magnesian rocks; 3. Hard siliceous rocks; the later intrusions of basic dykes and sills are referred to in connection with the Older Granite (see below).



1. Granite with pegmatite veins (p). 2. Talcose, chloritic, hornblendic, and other basic schists with green dolomitic rocks. 3. Banded ironstones, siliceous slates, etc. 4. Serpentine. d. Dykes. w. Worcester Reef horizon. Length of Section, approximately 4 miles.

Fig. 9. Generalized Section from Hilltop across the Jamestown Schist Belt, Barberton District, Transvaal Province.

The basic schists comprise green hornblende-schists, dark greenish chlorite-schists, greyish-yellow talc-schists and schistose basic rocks mainly composed of talc and carbonates, often with bright green chloritic partings resembling the so-called Mamba Bar of the Murchison Range very closely. This group is usually thinly bedded and soft, but there are also hard siliceous rocks, like those forming the country rocks in the Worcester Gold Mine, with vivid green soft talcose partings. Rocks of this kind are found right round the Mountain Land and are, at least in part, basic chloritic schists, profoundly altered through silicification and introduction of carbonate matter, while others may represent altered silicified dolomite (silicified talc-chlorite-calc-schists, impure silicified limestones, altered serpentine or dolomite). The majority of these talc-carbonate rocks lie within the contact belt of the granite and may have originated (in part) as serpentine, the conversion of which into almost pure talc rocks is strongly indicated in the Kaapmuiden-Malelane area. The carbonate portion is more often dolomite than calcite.

Among massive rocks rich in magnesia, serpentine is the most abundant, usually dark green, sometimes variegated and banded. The greatest development of serpentine lies in the north-western part of the Jamestown belt of Hills, where it includes a band over 2½ miles (4.02 km) wide, of great economic importance on account of its valuable and extensive asbestos deposits, e. g. in the New Amianthus Mines (see under Economic Geology). The beautiful green verdite also belong here, as well as the large bodies of talc near Malelane, where the alteration of highly magnesian rocks has also produced great bodies of magnesite.

Rocks probably of sedimentary origin form a long narrow band reaching from the Consort Mine to Eureka Siding and including the Lily Line. Round the Worcester Mine are banded siliceous rocks, such as banded calico rock, compact thinly bedded almost black siliceous slates and others, forming a series between 200 and 300 yards (183 and 274 m) wide and almost vertically interbedded with soft basic schists. These sediments are strongly metamorphosed by the intrusion of the granite forming the Crocodile Poort Ranges and are of great economic importance owing to their mineralisation (Consort Mine, Maid of De Kaap gold mines). Tourmaline is locally abundant in this aureole.

Both along the northern and southern margins of the Mountain Land very similar basic schists, and talc-carbonate rocks etc. (Pioneer Creek valley, etc.) are repeated, including hard greenish-grey quartzitic slates (entrance to Rimers Creek at Barberton). South of Barberton at the southern end of the series of carbonate rock is a remarkable grey dolomite conglomerate—15 feet (4,6 m) thick —with a crystalline dolomitic matrix in which lie scattered specks of almost black quartz. Its pebbles are nearly all chert, sometimes banded and range up to four inches in length, with smooth outlines. Many of them are intensely squeezed, and have acquired very sharply defined joint planes which cut clear across pebbles and matrix. The intense pressure to which the succession was exposed recalls the similar effects in the highly sheared Bevets Conglomerate of the Pretoria Series (see below).

Isolated minor occurrences of basic, massive and schistose rocks occur within Moodies Series (serpentine near Piggs Peak, talc-carbonate rocks of Hemsteede etc.).

Along the Noordkaap-Drakensberg Section, the series shows a gradual increase in thickness from west to south-east:—

	Approximate Thickness
North of Kaapsche Hoop	4000 feet (1220 m)
Worcester Mine	8000 ,, (2440 m)
Jamestown	14000 ,, (4267 m)

All the above group are strongly metamorphosed within the contact belt of the surrounding granite, with the production of contact minerals; this has a close connection with the distribution of gold bearing deposits (see under Economic Geology below).

Taken as a whole, the Swaziland System in this area shows several close analogies to the Pre-Cambrian complex of the Lake Superior Region. Thus the Lower Keweenawan, a great succession of basic and acid eruptive sheets with subordinate arenaceous beds and conglomerates, recalls the Jamestown Series, essentially a group of metamorphosed basic rocks, and including narrow belts of quartzitic slates, etc.; the succession of quartzites, slates, phyllites, carbonate rocks, conglomerates etc. forming the Upper Huronian, recalls Moodies Series with its abundant quartzites, argillaceous and local conglomerates; the widespread banded ironstones and other ferruginous slates correspond petrographically closely to the Negaunee Formation of the Marquette iron-bearing district, while both areas show very similar bands of red jaspery rocks; lastly, the intrusive Laurentian granite and gneissic granite of the North American Complex is paralleled by the intrusive Older Granite-Gneiss surrounding the Barberton Mountain Land.

b) The Murchison Range.

The Murchison Range lies in the Low Country[1] of the Eastern Transvaal, and extends from the Drakensberg for some 50 miles (80 km) through Leydsdorp in an east-north-easterly direction i. e. parallel to the principal trend line of the Barberton Mountain Land. It forms a succession of ridges and low often pointed hills, of which Spitzkop is the highest (2890 feet (908 m) above sea level). The Murchison Range is surrounded on three sides by granite and gneissic granite, apparently the same that occupies the whole of the country southwards to the Barberton belt of the Swaziland System; on the west it passes under the Black Reef Series of the Transvaal System. East of Leydsdorp the Murchison Range persists as a double line of hills, running approximately parallel. The more regular northern or Antimony Belt persists for some 20 miles (32 km), when it becomes more and more broken

[1] For details see A. L. Hall: "The Geology of the Murchison Range and District." Memoir No. 6, Geological Survey, Union of South Africa, Pretoria, 1912.

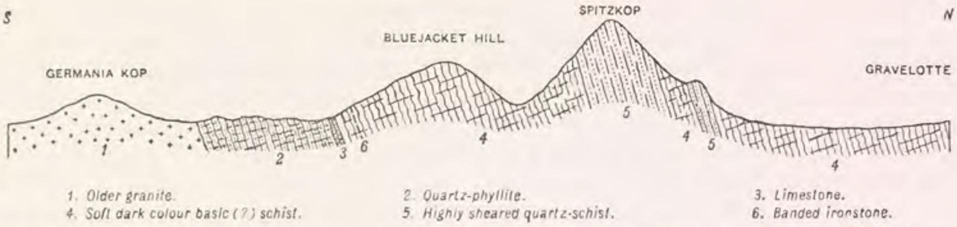


Fig. 10. Generalized Section across the Southern Portion of the Murchison Range at Spitzkop, Pietersburg District, Transvaal Province.

until it disappears in the granite. The southern line behaves similarly; both are gold-bearing (see under Economic Geology). Some of the principal features are determined by more resistant bands, e. g. banded ironstones, sheared quartzites, etc.

The Murchison Range comprises formations ranging from thoroughly quartzose to highly basic varieties. The commonest are: — Talc-schists, chloritic schists, chlorite-mica-schists, hornblende-schists, sheared conglomerates, banded ferruginous quartzites (calico rocks), dolomitic carbonate-rocks, various phyllites, etc. Some of the sediments closely resemble those from the Barberton District and from Mount Maré. The planes of schistosity are highly inclined to vertical and the strike departs but little from the general alignment of the range—which is sensibly parallel to that of the gneissic structur in the surrounding granite formation. From the Drakensberg roughly as far as Leydsdorp the dip is in general south or to the north, but beyond Leydsdorp eastwards the beds are commonly inclined to the north, and the dips are also higher (Fig. 10). The granite surrounding the Murchison Range is most probably intrusive.

Owing to the intimate association of schistose basic rocks with those clearly of sedimentary origin, a separation into distinct groups is not practical in the Murchison Range, but on the basis of close similarity in lithological characters and relationship to the intrusive Older Granite, one is justified to assign the rocks of that area also to the Swaziland System; the sediments, in particular, are most likely to be correlated with Moodies Series, as seen in the Barberton Mountain Land and at Mount Maré. The Pre-Cambrian Complex of the Low Country was affected by repeated systems of earth-movements following more or less the same direction, but finally ceasing before the intrusion of the system of younger basic dykes, which show no signs of shearing.

Outside the Murchison Range lie a few narrow belts, surrounded by granite, and made up of basic schists, massive serpentines, gabbroid rocks etc. usually appearing as isolated kopjes or low ridges, e. g. Kajaleri Kop, Valentine Kop and others. North of the main range a conspicuous belt of hilly ground—the Rooiwater Hills—extends for some 20 miles (132 km) from near Gravelotte to the Drakensberg; this has a width of three and a half miles and is made of massive basic rocks.

Lithologically the rocks of the Swaziland System in the Murchison Range and the associated smaller masses fall into a sedimentary and an igneous group. All the rocks are more or less profoundly altered as the result of intense pressure and shearing, but in comparison with the metamorphism in Moodies Series in the Barberton District and at Mount Maré, contact minerals are rare. Over the western end of the range, between Thabina and the Drakensberg, sedimentary rocks predominate, but from Leydsdorp eastwards, schists of igneous origin are more frequent than sediments, though crystalline dolomitic limestones locally appear. The banded ironstones, and especially the phyllites or quartz-phyllites are well marked and very much resemble those of Moodies Series at Barberton and Mount Maré.

Sheared Conglomerates occur near Thabina, near the old Gravelotte Mine and at Castle Kopjes; they form bands 6 feet and more in thickness, associated with finely laminated phyllites, or interbedded in sheared quartzites. The pebbles are markedly drawn out and flattened, and often lenticular in shape, while the matrix consists of greenish brown shaly or dark greyish brown quartzitic matter (Castle Kopjes); in the latter case there is a remarkably close resemblance to the sheared conglomerate of Mount Maré.

Banded ironstones or "calico" rock form at least three separate horizons (Coblentz, Gravelotte and Quagga). The most conspicuous is the southerly or Coblentz horizon; it consists of two steeply inclined bands, of which one is at least 30 feet (9,1 m) thick; such rocks are built up of alternating and regular layers of light coloured quartz and black or brown ferruginous matter; phases with contorted layers also occur.

To the sedimentary group may also be assigned the sheared quartzites, quartz-schists and quartz-phyllites, often determining conspicuous features—: Spitzkop, Louws Kop, Monarch Kop, Castle Kopjes, Jack, French Bobs, Tafel Kop, etc. One prominent band of sheared quartzites and quartz-schists runs from Tafel for over five miles eastwards into the summit of Spitzkop, whence it continues (intermittently) to the extreme eastern end of the range. A second band comprises Monarch Kop and is maintained as a prominent ridge through Castle Kop. Rocks of this type show a granular mosaic, optically disturbed quartz and other evidence of intense pressure; they are to be regarded as intensely (structurally) metamorphosed sediments; pale bluish grains of quartz resembling boiled sago are sometimes found.

Quartz-Phyllites, phyllites and allied forms are common in the western portion of the range from Leydsdorp to the Drakensberg and are soft thinly laminated greyish or brownish rocks, sometimes weathering into thin slabs; varieties pointing to an original arenaceous shale which has undergone strong shearing movement are typical of many outcrops; elsewhere there is a strong resemblance to impure and sheared quartzites. Certain hard whitish-grey quartz-phyllites south-west of Thabina carry stellate clusters of tourmaline, with relationships indicating shearing pressure acting concurrently with the introduction of tourmaline, and comparable to the deformed ottrelite crystals in the metamorphosed sediments of Mount Maré.

Carbonate Rocks carrying rhombohedral carbonates of lime and magnesia with or without iron occur repeatedly from the old Selati Mine to the Quagga beacon in the extreme east; they are holocrystalline with dolomite and quartz as their chief constituents. Occasionally there is also ankerite and magnesite. These carbonate rocks form more or less isolated outcrops from a few feet up to 200 feet (61 m) wide, when they rise locally into distinct features, e. g. Quagga Kop; probably the bulk of them originated as sediments; in some cases rocks of this group are carbonate bearing throughout, in others they are thoroughly quartzose with many calcareous bands up to two inches thick. The most striking type is the so-called Mamba Bar, forming part of the ridge of the Mashambane Mountains on Coblentz near Leydsdorp. It forms a calcareous zone a few yards wide, due to a very hard quartzose schist, always carrying bright green chloritic partings parallel to the planes of schistosity and causing through its high regular dip extensive regular dip slopes like bright green slabs-resulting in a conspicuous element in the scenery. The name is derived from the general appearance not unlike that of a snake's skin. Crystalline calcareous bands are well marked.

Probably also belonging to the Swaziland System, though not part of the Murchison Range proper, the Lulukop Limestone may be provisionally assigned to this carbonate group. It is a small irregular mass of coarsely crystalline metamorphic limestone covering about half a square mile over the slopes and summit of Lulu Kop close to the junction of the Selati and Olifants Rivers, and surrounded on all sides by syenite and pyroxenite of the Palabora Plutonic Complex; the rock owes its present character to intense (mainly thermal) metamorphism by this complex, in which the limestone was caught up. The Lulukop limestone is a very coarse holo-crystalline rock, generally pure white in colour, and practically without divisional planes; a very rare and faint banding emphasised by linear arrangement of some of the constituent minerals may represent original bedding planes. The bulk of the rock consists of pure opaque white calcite and magnetite, both in fairly large crystals, and very variable in relative amounts. Here and there are little "books" of muscovite up to two inches thick. Apatite is a very frequent acessory in greenish columnar crystals up to half an inch long. A very similar crystalline limestone was found in the workings of the Guide Copper Mine, some four miles north of Lulukop, as a very coarse rock containing admixtures of igneous pyroxene and orthoclase. Probably these ocurrences are analogous to the Port Shepstone Marble deposits in Natal (see below p. 46).

Schistose rocks of igneous origin are common throughout the Murchison Range and in the isolated similar belts surrounding it. They are usually basic, thoroughly schistose, and green or greyish in colour. Most of them are thoroughly schistose and include hornblende, talcose, chloritic schists and others, derived from originally massive rocks intrusive into the associated sediments. There are also less schistose and even quite massive rocks like the gabbroid types of the Rooiwater Hills or the serpentine of Kajaleri Kop; between these groups there are transitions indicating that the schists originated through structural metamorphism of massive rocks. Exceptionally there are siliceous schists which are derived through intense shearing of felsitic quartz porphyries (north of the United Jack Mine and west of Thabina) and are converted into light coloured quartz-sericite-schists, sometimes showing pale bluish "sago" quartz; some of them closely resemble the sericite-schists of Piggs Peak and Louws Creek in the Barberton District. Possibly also of igneous origin are lenticular masses of opaque white quartz, many yards long, and sometimes gold bearing.

For a comparison between the leading rock types of the Murchison Range and Mount Maré see below.

The intrusive relationship of the granite to the Murchison Range formations is indicated by the occurrence of granite apophyses cutting the igneous schists north of Pioneer Kop (Fig. 11) and by the inclusion of xenoliths of schists in the

1. Soft pale greenish grey hornblendic schists, traversed parallel and across the schistosity by quartzose granitic veins 1 to 2 inches in width.
2. White granitic vein, 4 feet.
3. Garnetiferous pegmatite vein, 3-4 feet.

Fig. 11. Section exposed in a prospecting trench at Dear's Old Camp north of Pioneer Kop, Murchison Range, showing the schists intruded by older granite.

granite (Haenertsburg). Since these igneous schists were derived as basic intrusions in the sediments, the latter also must be older than the granite and hence belong to the Swaziland System.

Owing to indefinite contacts with the granite, the thickness of the Murchison Range formations is uncertain, but it probably lies between 15000 feet (4572 m) for the western portion and 20000 (6096 m) for that east of Leydsdorp.

c) Mount Maré.

In the Mount Maré near Pietersburg, including a few scattered minor occurrences of schist, the Swaziland System forms a belt of country extending from near Uitloop, five miles north of Potgietersrust through the Yzerberg in a north-easterly direction through some 35 miles (56.3 km) as far as the Pietersburg-Haenertsburg main road, with a maximum width of about 3 miles (4.8 km). This direction is sensibly parallel to the main trend lines of the Swaziland System in the Barberton area and along the Murchison Range. The most important section is Mount Maré (close to Marabastad), a high straight range some 4 miles (6.4 km) long and built up of several subsidiary ridges, determined by resistant banded ironstones. This range ends towards the south-west against the powerful Yzerberg Fault through which the Mount Maré section is cut off and displaced into the Yzerberg-Uitloop position. The Yzerberg, 11 miles south-west of Marabastad, is a very striking hill of peculiar shape owing to its crest line rising into two sharp peaks like the back of a double humped camel. It is built up of banded ironstone dipping steeply to the south-east. Further towards the south-west the faulted Swaziland System forms another powerful ridge composed of strongly sheared quartzites and flanked by soft basic igneous schists.

Outside Mount Maré minor schist patches lie on Roodepoort south of Pietersburg, and on Palmietfontein, and form several low extensive kopjes over the farms Eersteling, Turffontein, Waterval and Vrischgewaagd, composed mainly of fine-grained igneous schists with occasional compact siliceous schists, probably representing highly sheared sediments. Minor granitic areas lie within, and completely surrounded by, such schist belts, and in their lenticular shapes indicate apophyses from the main mass of intrusive granite.

The succession in Mount Maré shows many kinds of schists, nearly all of sedimentary origin belonging to Moodies Series; they comprise banded ironstones (calico rock), quartz-schists, sericitic quartz-schists, sheared quartzites, various phyllites garnet-schist, sheared conglomerates, etc. The average dip is towards the south, while the strike runs with that of the range. Towards its extreme ends the beds are highly disturbed and contorted, specially close to the Yzerberg Fault. This great break causes the abrupt termination of Mount Maré at the western extremity of the range. In the neighbourhood of the Yzerberg, the striking escarpment of the Strydpoort Range due to the quartzites of the Black Reef Series comes to an abrupt termination, and reappears close to the Potgietersrust main road about 11 miles further west; the prominent band of calico rock of which the Yzerberg is composed is cut off by this fault at both ends. There is reason to believe that the same great fault extends roughly along the main road at least as far as the western portion of Mount Maré, and the displacement of the Black Reef Series is approximately the same as that of the calico rock between Rietvlei near the Yzerberg and the point where it is last seen in the extreme western portion of Mount Maré. It is probable that the particular horizon of banded ironstone at the former locality is the Uppermost Band, since north of the Yzerberg it is underlain by red Slates similar to those seen on Hollands Drift. The calico rock in both places is highly contorted, but in the more westerly occurrence the quartzite bands are pink and jaspery. The range of sheared quartzites, etc. beginning at the Yzerberg and extending south-westwards is therefore the faulted and displaced continuation of the Mount Maré Range; it finally disappears under the Black Reef Series of the Transvaal System.

The sequence across Mount Maré (see Fig. 12 on Plate II) is as follows:—

	Approx. Thickness in Feet	(m)	
Uppermost Banded Ironstone	100	30.5	Upper Mount Maré Series (top not seen) 3180 feet (969 m)
Red Slates	800	244	
Upper Banded Ironstone	30	9.1	
Red Shales, Phyllites; Pale greenish compact Schists, Quartz-Schists, with thin slightly sheared Conglomerates	1350	411	
Coarse Conglomerates with well-rounded Pebbles; Ottrelite- and Andalusite-Schists	900	275	
Middle Banded Ironstone	20	6.1	Middle Mount Maré Series 620 feet (189 m)
Quartzitic, Chloritic and other Schists	600	183	
Lower Banded Ironstone	50	15.25	Lower Mount Maré Series (base not seen) 750 feet (230 m)
Quartzitic and Compact Green Schists	200	61	
Lowermost Banded Ironstone	50	15.25	
Hard compact greenish Chloritic Schists and sheared Quartzites	250	76.2	
Highly sheared Conglomerate with Tourmaline Veins	5	1.5	
Green sheared Quartzites and Schists	200?	61	

Unconformity,
Sheared and Massive Granite with basic igneous Schists.
Total Thickness . . . . 4,550 feet (1387 m)

Since neither the base nor the top is seen the true thickness is uncertain, but there is no evidence of repetition by folding.

Banded Ironstones or Calico Rock occur at three horizons, comprising five distinct bands up to 100 feet (30.48 m) thick; of these the single band of the middle horizon determines the highest and most persistent ridge, the uppermost (thickest) band being the one which becomes so prominent in the Yzerberg. These rocks are remarkably persistent, resemble one another closely, but are in association with different sets of strata.

In their lithological characters they closely resemble the banded ferruginous sediments in the Barberton area and the Murchison Range.

Conglomerates occur in two varieties; the one is very intensely sheared, the other almost non-sheared. The sheared conglomerates lie below the lowest banded ironstone in pale greenish quartzitic schists and form a band five feet thick; it is a light greyish rock made up of many quartzitic pebbles lying in a scanty matrix of quartzite. Cutting across it are many veins, usually less than one quarter of an inch thick, composed of deep green cross fibre tourmaline in very delicate and densely packed needles. The pebbles are often elongated or flattened, often drawn out into lenticular shape; they consist of quartzite and quartz, showing a length from

6 to 16 times the width. Shearing has been intense, though not sufficient to mask entirely the origin as a conglomerate. Two minor bands lie a little above the middle ironstone horizon, but are much less sheared and without tourmaline. The second group of conglomerates occupies a position well above the middle ironstone and includes one bed 30 feet thick, merging gradually into soft reddish quartzitic schists with scattered pebbles. The latter (also those in the conglomerate) are well rounded, up to 4 inches long, and due to milky quartz; they are hardly sheared at all and much less plentiful. Their matrix is pale pinkish or dirty yellow quartzitic matter, without tourmaline. These variations in the intensity of shearing and in content of tourmaline are due to the contact between granite and sediments forming a favourable zone for shearing and permeation with tourmaline, due to the intrusive character of the granite.

Schists with ottrelite or andalusite, or both these minerals occur in the upper part of the succession. They are well bedded slaty rocks, in which the content of metamorphic minerals shows much variation; thus thin pale greyish layers a few inches thick and containing both ottrelite and andalusite alternate with bands free from these. Slates almost free from andalusite are pale greenish and crowded with many scattered flakes of bright green ottrelite. Rocks almost free from this mineral often are rich in andalusite and then assume a dark greyish carbonaceous appearance. Weathered surfaces in such cases are characteristically knotted, due to irregular dirty white patches of andalusite. Both minerals are much deformed and indicate that intense shearing pressure was associated with their formation; they cannot therefore be regarded as due to pure thermal metamorphism.

Quartz-Schists and sheared green quartzites, chloritic schists, phyllites and red slates make up the bulk of the succession. Green compact chloritic schists predominate in the lower horizons specially near the lowermost banded ironstone, and the quartzitic schists and sheared green quartzites are most in evidence above and below the Middle Ironstone; typical red slates account for some 1200 feet (366 m) of the succession near the uppermost ironstone band. In the siliceous phases tourmaline is widespread, sometimes seen as dark coloured veins, elsewhere only found in thin sections. In the prominent range of sheared quartzites south-west of Mount Maré beyond the Yzerberg, occur rocks in every respect identical with the above varieties, and also carrying tourmaline.

Large masses of pure dull white quartz, many yards long, occur on Witkop, immediately north of Mount Maré, on Weltevreden and Palmietfontein near Pietersburg (sometimes gold-bearing) and correspond to similar lenticular masses in the Murchison Range.

Compared with Barberton, rocks corresponding to the Jamestown Series are only represented by a feeble development of basic schists in Mount Maré itself, but are very prominent in the isolated occurrences referred to, e. g. Palmietfontein, Turffontein, etc. which consist of talcose, hornblendic and other schists. Carbonate rocks like the Mamba Bar of the Murchison Range are also found here. The Onverwacht Volcanic Series is not found in the present belt.

The following table gives a summary comparison of the principal features at Mount Maré and in the Murchison Range:—

	Murchison Range, etc.	Mount Maré, etc. near Pietersburg
Sheared Conglomerates	Castle Kopjes, Gravelotte, Maake's Location	Well represented in five separate bands
Banded Ironstones	Coblentz, Gravelotte, etc.; at least two distinct bands	Conspicuous ridges along three horizons
Sheared Quartzites and Quartz-Schists	Spitzkop, Jack, Louws Kop, Monarch Kop; two separate belts	Prominent on north side and from Yzerberg to Potgietersrust
Quartz-Phyllites	At several localities	Well represented on south side
DolomiticSchists andLimestones	Mamba Bar, Coblentz; west of Castle Kopjes, at Quagga beacon, etc.	Mamba Bar on Roodepoort. Carbonate-Schists on north side of Mount Maré
Amphibolite-, Talc-, Chlorite-Schist, etc.	Well represented throughout	Poorly represented, except at eastern end, e. g. Palmietfontein
Tourmaline in Older Granite	Tourmaline occurs in the granite	Tourmaline occurs in the granite
Metamorphic Tourmaline in Schists	Metamorphic tourmaline found in the phyllites west of Thabina	Metamorphic tourmaline abundant and conspicuous in the quartz-phyllites
Ottrelite and Andalusite Slates	?	Abundant at the Zandrivier mynpacht
Schistose Character and cataclastic structures	Nearly all rocks highly schistose; cataclastic structures common	All rocks highly sheared and cataclastic
Relationship of Older Granite	Intrusive	Intrusive

The intrusive relationship of the surrounding granite follows from the existence of granitic apophyses, e. g. between Witkop and the eastern end of Mount Maré, and on Roodepoort south of Pietersburg, where the granite becomes distinctly banded and finer-grained at its junction with mica-schists. It also follows from contact metamorphism, e. g. formation of lustrous mica-schists carrying abundant biotite with typical thermo-metamorphic habit (Roodepoort) or of micaceous garnetiferous quartzites, giving rocks very closely resembling the Pretoria Series in the Haenertsburg Goldfields, thermally metamorphosed by the Bushveld Igneous Complex. The very widespread abundance of tourmaline also supports the intrusive nature of the granite.

d) South Eastern Transvaal[1].

In this area there are two groups of rocks older than the old granite and therefore included in the Swaziland System. Near Piet Retief the granite is intrusive into patches of quartzites, mica-schists and basic igneous rocks, massive and schistose. These strike in a general S.W.-N.E. direction and usually have steep dips, indicating intense folding.

The second group of rocks with which the granite is in intrusive contact is younger than the first. It occupies a large area in the south-eastern Transvaal and extends into Natal and Swaziland. The Pongola Series, as these rocks are called, consists of a lower division of quartzites, phyllites and contemporaneous lavas, and an upper division of shales and quartzites.

[1] This section has been kindly contributed by Dr. L. J. KRIGE, Senior Geologist, Geological Survey, Union of S. Africa.

The following table shows the probable correlation with the Swaziland System in the Barberton District.

Tentative Correlation Table.

S. E. Transvaal.	Barberton.
Upper Pongola Series.	Upper part of Moodies Series or absent.
Lower Pongola amygdaloidal lavas.	Onverwacht Volcanic Series.
Lower Pongola sedimentaries. Quartzites and mica-schists, forming patches in the old granite.	(Part of) Moodies Series.
Basic rocks associated with the quartzites and mica-schists in the granite.	Jamestown Series.

The Pre-Pongola Rocks.

These rocks occupy two large areas, each over 10 miles long, west of Piet Retief, and there are several smaller patches enclosed in the granite. They consist of altered sediments and basic igneous rocks.

The metamorphosed sediments include massive and schistose quartzites, micaceous quartzites, mica-schists and phyllites, chert and jaspilites. The schists and quartzites sometimes contain garnets, and staurolite also occurs. One small outcrop was found of a conglomerate or breccia, with quartzite and chert pebbles up to 3 inches (7.6 cm) long. The banded ironstone rocks, as well as the mica-schists and phyllites are often intensely folded and contorted. The dips are generally steep (50 to 90°) and there is probably isoclinal folding. It is therefore not possible to calculate the thickness with any approach to accuracy, but 3000 feet (915 m) seems to be a reasonable estimate. There cannot be much doubt that these rocks represent part of the Moodies Series.

The Basic Igneous Rocks are schistose or massive. They consist chiefly of amphibolites and amphibole-schists, but there are also pyroxenites and peridotites, talc-schists, serpentine and volcanic tuff. These rocks occur in association with the quartzite and mica-schist group and, like these, they have been intruded by the old granite. The basic rocks must therefore be assigned to the Jamestown Series.

The Pongola Series.

This series is sub-divided into the Upper and the Lower Pongola Series. (See Fig. 13.)

The Lower Pongola Series consists of three groups of quartzites and phyllites, each overlain by a thick layer of amygdaloidal lava (usually andesite). As a rough approximation, the thickness of each sedimentary group may be taken as more or less 1000 feet (305 m), while 2000 (610 m) or 3000 feet (915 m) may be allotted to each lava bed. North of the Assegai River the Lower Pongola Series is represented by only one group of quartzites and one lava bed, probably the highest of the three.

The Upper Pongola Series consists of shales with two thick and several thin intercalated beds of quartzite. There seems to be an unconformity between the Lower and Upper Pongola Series; north of Piet Retief the lavas of the Lower Series are directly overlain by the quartzites of the Upper Series, while east of Piet Retief the quartzites are separated from the lavas by 2000 feet (610 m) of shales. These shales have, to a large extent, undergone metamorphic changes. They now consist of sandy shales, slates, chiastolite-slates, phyllites, ottrelite- and andalusite-schists. Andalusite-schists also occur in the shales separating the two thick quartzite groups.

The quartzites are light-coloured massive rocks with a fine or medium grain. Occasionally very fine grains fill the spaces between larger grains, producing a kind of sago-structure. The quartzites contain a number of conglomerate beds, up to 8 or 10 feet (2.44 or 3.05 m) thick, some of which carry gold. The pebbles are usually less than an inch across, but sometimes they reach diameters of 3 or 4 inches (7 or 10 cm). They consist chiefly of quartz and quartzite, but chert and schists are also occasionally represented.

The quartzites are followed by a great thickness of shale and mudstone, containing thin beds of quartzite. The shales and mudstones are generally ferruginous and coloured grey or green when fresh, red when weathered. They contain four thick beds of magnetic iron ore, three of which are near their base. The ore is sometimes accompanied by jaspilite, often contorted, and near the top of the series there is a conspicuous contorted jaspilite bed. At present the Upper Pongola Series is about 8000 feet (2440 m) thick north of the Assegai River, but probably a considerable thickness has been removed by denudation.

In the Transvaal the Lower Pongola rocks have been invaded by gabbro, granophyre, and associated rocks. These intrusions were sometimes anterior, sometimes posterior to the granite intrusion. They therefore probably represent differentiates from the granite magma.

On the Transvaal-Natal border the Upper Pongola Series contains a large number of sheets and dykes of diabase. These are not present north of the Assegai River.

The Pongola beds occupy two centroclines on the Transvaal-Natal border. In the Transvaal they form a syncline, striking S.E.-N.W. These structures are complicated by minor folds, in addition to faults and thrusts. The metamorphism of the Pongola shales is due chiefly to the granite intrusion, the mountain-building forces playing a subordinate part.

Correlation.

It is generally assumed that the granite in the central Transvaal, which is older than the Witwatersrand System, and the granite of the eastern Transvaal are of the same age. On this assumption, the Pongola rocks, which are older than the granite, cannot belong to the Witwatersrand System. On the other hand, Moodies Series is represented in part by the quartzites and mica-schists occurring in association with basic rocks of the Jamestown Series, in the granite to the west of the Pongola beds. The Pongola Series must therefore be intermediate in age between the older portion of Moodies Series and the Witwatersrand System, if the two granites are the same.

The Pongola lavas and the Onverwacht Volcanic Series of Barberton have several points in common. Both consist largely of basic amygdaloidal lavas, containing bands of ferruginous chert and intruded by acid and basic rocks (quartz-porphyry, granophyre and gabbro). Both are older than the granite and younger than the older members of Moodies Series. They are separated by a comparatively small width of granite. There is therefore ample justification for regarding the rocks of the Onverwacht Volcanic Series as an outlier of the Pongola lavas.

As the northern extension of the Pongola rocks contains only one lava bed (the highest) it is probable that this is the lava represented in the Onverwacht Series, perhaps in addition to the lower ones. Therefore, if the sedimentaries of the Lower Pongola Series are represented in Barberton, it must be by that part of Moodies Series immediately underlying the Onverwacht Series. If Moodies Series contains beds younger than the Onverwacht Volcanic Series, then these correspond to the Upper Pongola Series.

In the accompanying stratigraphical section the thicknesses in the Upper Pongola Series refer to the area north of the Assegai River, while the thicknesses in the Lower Series are rough estimates.

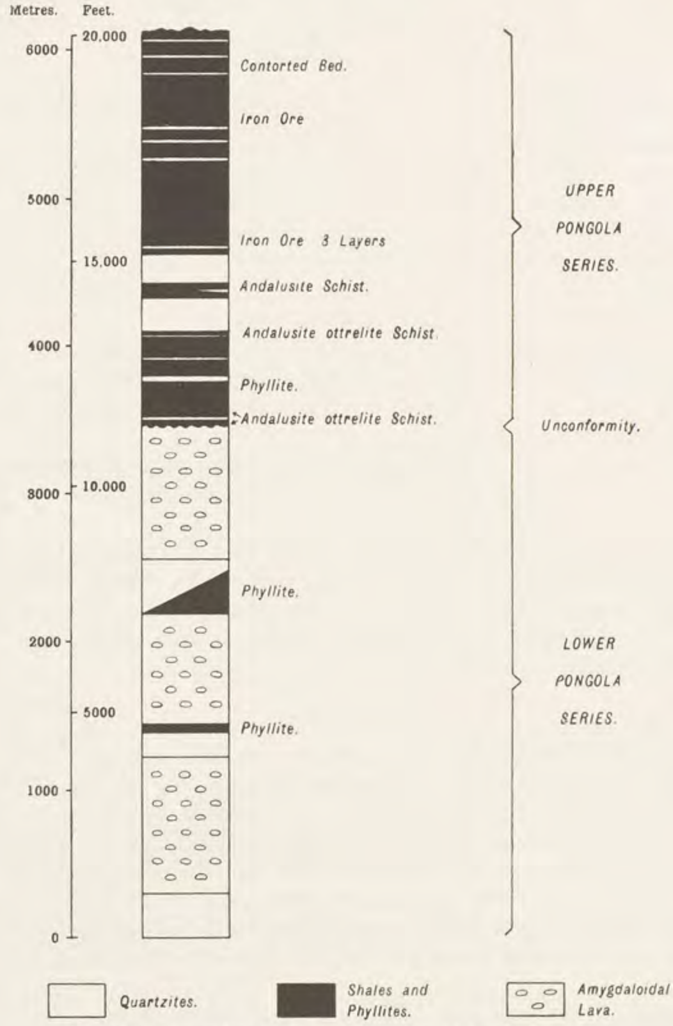


Fig. 13. Generalized Vertical Section of Pongola Series.
Erratum in the Figure: "Iron ore 3 (not 8) layers".

e) Natal, including Zululand[1].

1. The Nondweni Schists. At Nondweni a complex formation, cut by the "Old Granite" of the region, appears in the form of inliers in the Dwyka, which, although of limited extent, is important in furnishing a link between the ancient rocks of Natal with those of the Vryheid-Barberton districts. They consist principally of tough "greenstones", much cleaved and sheared, which, from the preservation of vesicular structures, are lavas, and for the most part are of andesitic composition. Intercalated are thin fine-grained quartzites and black and white cherts, the latter not improbably due to the silicification of lavas or tuffs. At the Sister's

[1] This section has been kindly contributed by Dr. A. L. du Toit.

Hill close to Nondweni in addition to silicified andesite and silicified quartz-felsite, soft calcareous schists occur with bars of chert and quartzite and also some impure dolomite.

At two points in this little area this formation is unconformably overlain by strata containing "bankets" composed largely of black chert pebbles, which have been correlated with the Insuzi Beds (see below).

In the Mazabeku valley, a tributary of the Buffalo River far to the south-west, similar dark and occasionally vesicular greenstones are invaded by granite, while intercalated are fine-grained cherty or striped quartzites (greenish, grey, black or other colours), also intrusive ultrabasic rocks. The group is overlain with strong unconformity by the base of the main body of the Insuzi Beds. In its general facies this group agrees with the Jamestown Series of the Barberton district, hand specimens of which can be matched with those from Zululand.

2. The M'fongosi Schists. This—probably equivalent—group emerges from beneath the Karroo Beds in the Tugela Valley, extending from just below the Tugela Ferry in an easterly direction past M'fongosi, and crossing the lower Insuzi and Umhlatuzi valleys to fade out in the granite of the Melmoth district. The dip is usually to the south, but this is ascribed to inversion: the N. boundary is generally with the Insuzi Beds.

A broad zone running along the centre of this belt consists of greenish phyllites and chlorite-schists, which pass upwards into grey or pink limestones and dolomites [400 ft. to 500 ft. (122 to 152 m) thick at Nhlotohana] and downwards through green grits, basic tuffs, lavas and cleaved greenstones into hornblende-schists and amphibolites, cut and much veined by granite, pegmatite and aplite.

Indeed further down the Tugela Valley, and again between Eshowe and Empangeni these hornblende rocks have a great development, being veined and interlaminated with granitic matter to such an extent, as to pass into composite hornblende granulites and gneisses. Prior to their intrusion by the granite they were invaded by masses of serpentine, e. g. Fort Yolland, Sitilo, Tugela Randt, in which seams of chrysotile-asbestos have been found. Towards Isibudeni and south of Melmoth the group includes banded ironstones.

3. The Insuzi Beds. These occupy a wide area but only show through the Karroo where valleys have been cut down deeply as in the Buffalo, Insuzi and Umhlatuzi gorges. The beds are bent into fairly open folds in the west and north, but are tilted at high angles in the south, and become invaded by the Old granite on the east with the development of contact rocks carrying andalusite, kyanite and occasionally staurolite. A strip runs between Nkandhla and Melmoth and the formation occurs again in the White Umfolozi Valley in the neighbourhood of the Denny Dalton Mine.

Essentially the group consists of a number of bodies of fine to medium grained quartzite, often sugary or gritty and with occasional pebbles. Now and again the latter are numerous enough to form thin conglomerates, the inclusions consisting of quartz, quartzite, black and striped chert etc. (derived from the groups 1 and 2) These are the „Insuzi Bankets", and are auriferous in places. The quartzite bodies —from 50 to 500, or more feet (15 to 152 m) thick—are parted by basic amygdaloids and chlorite-schists (due largely to the shearing of the volcanics), tuffs and phyllites with a zone of banded-ironstones. They have been penetrated by great sills of peridotite, diorite and a syenitic rock (in which copper is present).

There can be little doubt that these beds correspond fully with HUMPHREY's Lower Pongola, the higher and purely sedimentary formation of the Upper Pongola being represented, but in a limited degree in the south. South of the Tugela these rocks have not been observed.

In addition extreme thrusting has pushed the M'fongosi schists over a conglomerate-grit formation that rests unconformably on the Insuzi Beds, the whole having been planed down and covered by horizontal Table Mountain sandstones later. Its age is uncertain.

4. Crystalline metamorphic limestones occur in the M'fongosi and N'hlotohana valleys below the junction of Tugela and Buffalo Rivers, but the most important occurrence is the Marble Delta near Port Shepstone. Some five or six miles west of this locality and in the valley of the Umzimkulu River lies a tract of marble (almost wholly dolomitic), nearly four miles long by about two miles broad, surrounded on all sides by granite and gneiss. The marble forms a bent and twisted mass enveloped by the igneous formation, which underlies it at a shallow depth and forms great inclined or nearly vertical intrusive sheets cutting across it and separating it into distinct portions. On the eastern side are several parallel sills of granite parted by layers of marble isolated in the gneiss arranged round the principal mass. The latter is not less than 2000 feet (610 m) thick and is split up into an upper and lower group by means of a belt of quartz schist about 50 feet thick.

The limestones are medium to coarse grained white rocks (occasionally grey) in which the bedding planes are emphasized by lines of contact minerals standing out clearly on weathered surfaces; much of the limestone is pure, the percentage of silicates varying from up to five; these consist of olivine—altered to pale-yellowish or greenish serpentine—greenish diopside, white tremolite, coppery coloured phlogopite-mica, orange coloured chondrodite (whith clinohumite), grey spinel and a little graphite. Along the granite-dykes there has been interchange of material across the active surfaces of contacts leading to reaction borders—e. g. diopside-scapolite-rock, phlogopite-calcite-rock, and ophicalcite. Under the influence of the granite intrusions the dolomitic marble has been converted into calcite through the complete removal of the magnesia, leading to calcitisation; in this way masses of coarsely crystalline calcite result. The marble originated as magnesian limestone, since converted through thermal (aided perhaps by static) metamorphism into crystalline dolomitic marbles, dedolomitized in places through the diminution of carbonic acid and its replacement by silicic acid. Besides the normal type of contact metamorphism, there has been contact metasomatism (transfusion) in the immediate proximity to contacts. Loss of the bulk of the magnesia in certain cases and formation of calcite (calcitisation) was probably caused by the action of carbonated waters during the cooling of the plutonic complex.

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B. The Northern Area.

By

A. W. ROGERS.

In Bechuanaland, Gordonia, Prieska, Kenhardt and Namaqualand there are areas of sediments and volcanic rocks older than the Ventersdorp and Nama systems and, in most instances, older than what are regarded as the Old Granites and Gneiss. The largest of these areas stretches from a point north of Upington 160 miles (257.5 km) south-eastwards, with a maximum exposed width of 40 miles (64 km), forming the hilly country on the borders of Prieska and Kenhardt. These rocks have been called the Kheis series and subdivided into three groups:

3. Wilgenhout Drift beds,
2. Kaaien beds,
1. Marydale beds.

The structure of the area is complicated and the three groups are invaded by gneiss,while large masses believed to belong to the two lower groups lie in the gneiss at distances up to 60 miles (96.5 km) from their main outcrops. The Wilgenhout Drift beds form an anticline with a core of Kaaien beds near the Orange River, and this is taken to be the normal succession; the Marydale beds occur on the flanks of the main Kaaien outcrops and are abundantly represented in the detached areas surrounded by gneiss; these facts led to the adoption of the order of succession given above. The original base of the Marydale beds has not been recognised; there are pale granulites associated with the lower beds, possibly representing more ancient granite or other rock in a highly altered form, but no positive evidence for this hypothesis has yet been brought forward. The total thickness of the Kheis series must be very considerable, each group being probably some thousands of feet thick, but enough work on them has not been done to afford useful estimates.

1. The **Marydale beds** include arkose, quartzite, slates, mica-schists, limestones, banded magnetite-quartz-rocks, a variety of hornblende-schists, granulites and other highly metamorphosed rocks. Some of the hornblende-schists are amygdaloidal and probably represent lavas; others are altered intrusions, but the original nature of the greater part remains obscure. The hornblende-schists and granulites are often garnetiferous. The limestones usually contain secondary silicates, scapolite, olivine, humite, diopside, phlogopite and green spinel being the most abundant. The thickest belt of limestone measured was 1200 feet (366 m), in a detached mass in Kenhardt.

2. The **Kaaien beds** are almost entirely mica-schists, quartz-schists and quartzites. Felspar is abundant in places where the rock grades into pale granulites. Some epidote and magnetite are often present, but magnetite in sufficient abundance to colour the rock grey or black is rarely seen, and then only in thin bands of small extent. No development of magnetite-rocks comparable in thickness and extent with those in the Marydale beds has been found in the Kaaien beds. The Kaaien beds form hilly and mountainous ground stretching 100 miles (161 km) from southern Prieska to the Orange River, where they are continued in two directions, northwards for 140 miles (225 km) to the Kuruman River and north-west past Upington for 60 miles (96.5 km). The eastern branch is for the most part covered with sand, and perhaps also by the basal Karroo beds, but it forms the very conspicuous and steep-sided Scheurberg.

3. The **Wilgenhout Drift** beds are less altered than the two lower groups, and evidence of their conformable succession on the Kaaien beds is given by the parallelism of beds in each group round a plunging anticline south of and near the Orange

River on the farm Karos. The beds consist of sheared green lavas, breccias, slates, red quartzites and conglomerates, limestones, magnetite-quartzites and quartz-porphyries which are probably lavas.

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The **Kraaipan Series.** In Bechuanaland and the neighbouring part of the south-western Transvaal there is a thick group (over 10000 ft. [3048 m]) of banded jaspers and ironstones, cherts, schists of various kinds, impure limestones, and volcanic rocks of basic and acid composition which are not known to have been invaded by granite. The contacts are rarely exposed, but those observed are faults or believed to be normal unconformities. Near Abelskop in the south-western Transvaal, 70 miles (113 km) south of the type locality, there are similar beds with some pure limestones in addition, described by E. JORISSEN; he found the schists to be invaded by aplite and granite; 60 miles (96.5 km) west of these outcrops, slates and magnetite quartzites are exposed below the Black Reef beds in the Vryburg district, but here no definite evidence of the relation of the gneiss to the sedimentary rocks has been found. All these outcrops are believed to belong to the Kraaipan series, and they present obvious resemblances to parts of the Kheis series. In the Mafeking district the largest area of Kraaipan beds extends some 20 miles (32 km) northwards from Kraaipan station; resting on gneiss are mica-schists followed by 60 feet (18.3 m) magnetite-quartzites and then similar rocks interbedded with chlorite-schists and phyllites; thick cherts lie on these beds and are followed by more phyllites, magnetite-quartzites, and cherts. The Madibi area to the east consists of similar rocks which have been prospected for gold; they are traversed by fractures in which quartz and pyrites are in places accompanied by certain amounts of gold. The character of some of the granite contacts in this area are rather uncertain. Some 25 miles (40.2 km) west of the Kraaipan area a series of outcrops appear from beneath the general cover of sand through a distance of 50 miles (80.4 km); they include considerable thicknesses of rhyolitic and andesitic or basaltic lavas and tuffs in addition to the other kinds of rock occurring in the eastern areas.

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Maps. Cape Sheets 50, 52.

C. The Western Area.

By
A. W. ROGERS.

Considerable areas of schists, granulites, altered limestones and paragneiss containing much sillimanite and garnet occur in the pre-Nama gneiss of the north-west, though no area of such rocks comparable in size with the main mass of the Kheis series in Prieska, Kenhardt and Gordonia has yet been found in Namaqualand. When the intervening area in Bushmanland and western Kenhardt [200 miles (322 km) wide] has been examined it may become desirable to include all these rocks in the Kheis series. Above Sendling's Drift on the Orange River there are green schists of uncertain origin in the gneiss, and above Viol's Drift thick belts of amygdaloidal volcanic rocks have been converted into granulites. In the copper mining region of Ookiep and Nababeep sillimanite-cordierite-gneiss and quartzites rich in sillimanite form a considerable part of the gneissose country rock penetrated by the ore-bearer intrusions. In the Kamiesberg and between it and the coast there are numerous bodies of altered sediments, including limestones, and dark granulites and schists in which amygdaloidal structure is preserved.

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Map: Cape Sheet 19.

D. The Older Granite.

By

A. L. HALL.

The term Older Granite is applied to an extensive granitic and in part gneissic formation occupying large tracts in the Transvaal, Natal and Swaziland as well as in the Cape Province and also represented in the northernmost portion of the Orange Free State (see Fig. 14). This formation is described as the "Older" to emphasize its distinction from the so-called "Newer" granite, also called the Red or Bushveld Granite (see section 5, p. 105); the latter is confined to the Bushveld Complex (section 5, p. 96) and is post-Transvaal System, while the former is pre-Transvaal-Nama System in age. Though the numerous and widely distributed occurrences of Older Granite are at present grouped into one unit, it is highly probable that this embraces granites belonging to more than one period of intrusion; in the eastern Transvaal one such period is separated as the Palabora or Mashishimala granite (see below p. 54).

Both in handspecimens and microscopically the Older and Newer or Bushveld Granites are quite distinct; the following table[1] gives the principal characters of the two formations:—

	Older Granites	Newer or Red Granite
Colour	Grayish white, rarely red	Pale pink to red; very rarely gray
Felspars	Microcline and plagioclase	Orthoclase, microperthite, etc.
Ferro-magnesian Elements	Biotite, or biotite with hornblende, or biotite with muscovite	Biotite, or biotite with hornblende, muscovite very rare
Structure	Massive, but often gneissic	Massive
Pegmatites	Very common	Very rare

In the northern and north-eastern parts of the Union the Older Granite occupies a large proportion of the Transvaal and Swaziland. Including a few small scattered patches in the western Transvaal, and the granitic areas in Natal and Zululand, not less than 30000 square miles (77695 qkm) of country are occupied by the Older Granite formation. The bulk of this area forms a broad strip of country some 60 miles (96 km) wide running nearly north and south through Swaziland and the eastern Transvaal almost to the northern border of the last named province, and

[1] Based on G. A. F. MOLENGRAAFF: "Géologie de la République Sud-Africaine du Transvaal." Paris, Bull. Soc. Géol., 1901, pp. 13—92.

continued westward to the western border of the Transvaal. Most of this belongs to the Low Country, but the granite is also represented over much of the plateau like region extending from Pietersburg northwards to Louis Trichardt and from Bandolier Kop westwards to the Sand River and beyond.

In the eastern and north-eastern Transvaal the Older Granite occupies the country situated between the Lebombo Range (Karroo System) on the east and the Drakensberg (Transvaal System) in the west. Along the eastern slopes of this feature the Older Granite passes with a purely sedimentary contact under the quartzites and conglomerates of the Black Reef Series forming the base of the Transvaal System, which frequently develops an arkose, composed in part of material derived from the granite. Large hummocky outcrops of massive granite are characteristic of much of this formation, and are a very striking feature, e. g. in the Crocodile Poort granite hills between Nelspruit and Kaapmuiden, as well as in the country surrounding Embabaan in Swaziland. The granite formation includes both thoroughly massive rocks and others with gneissic habits, as well as true gneiss, but commonly these variations are not sharply defined from one another and are due to differential movement during consolidation. At many localities the granite has small irregular patches of basic schists in it, e. g. hornblende-schist, talc-schist, chlorite-schist, which belong to an older group, invaded by the granite. The most extensive occurrences are referred to above. Under the abnormally high rainfall along the Drakensberg chemical weathering decomposes the granite down to depths of 50 feet (15 m) and more, and thus gives rise to typical "Badland" scenery along the foot slopes of that range, while conspicuous earth pillars are locally produced.

The Older Granite as developed round Nelspruit is typical of large areas within the Crocodile River valley, and elsewhere in the eastern Transvaal; basic patches, often spheroidal in shape, are common and consist almost entirely of very fresh biotite and some hornblende, while the formation also carries many coarse masses of white pegmatite, composed of quartz, orthoclase and large plates of biotite. The normal rock is a greyish white medium to coarse grained massive biotite granite, sometimes passing into muscovite bearing varieties. Microscopically the granite is characterised by dirty greenish brown biotite, together with quartz, orthoclase, microcline and the usual accessories. Between Elandshoek and Alkmaar (and elsewhere) near its contact with older schist masses, the granite passes through faintly oriented phases into gneissic granite and gneiss, with locally tourmaline bearing varieties. Round Hilltop south of Nelspruit the massive pale greyish or slightly pinkish normal granite becomes darker and gneissic, and is traversed by many pegmatite veins up to 15 feet (5 m) thick, the planes of gneissic structure being sensibly parallel to the strike of the adjoining Jamestown belt of schists. This progressive development of gneissic structure is not accompanied by cataclastic phenomena and is due to the intrusive character of the granite. Near Hectorspruit the latter carries veins of red fine-grained material up to several yards thick, composed of orthoclase and quartz with some microcline; such rocks denote a slightly later period of intrusion.

On the south side of the Barberton Mountain Land the Older Granite occupies many square miles of country and continues southwards well into Swaziland; between Forbes Reef and Embabaan are dark grey highly acid modifications with very little mica, as well as very coarse varieties with large crystals of orthoclase. West of the Ingwenya Range at Suicide Kop are bright brick red variations.

The granite of the De Kaap valley has a composition distinct from that of the normal Older Granite, and differs from it markedly also in handspecimens; this variety occupies the whole of the valley between Barberton and the Drakensberg at the Devils Kantoor. The De Kaap valley granite is white or pale green, nearly

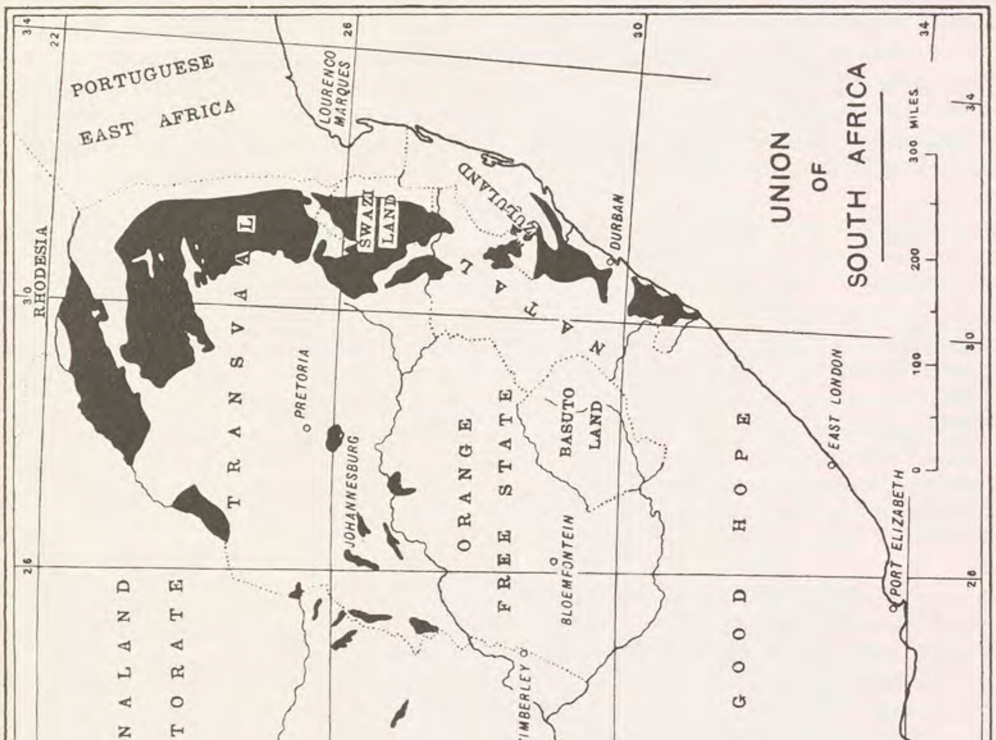

Fig. 14. Outline Map showing the distribution of the Older Granite.

always strongly mottled by dark green hornblende, and more often slightly banded than massive, specially near its contact with older formations; bright green amphibole is practically the sole ferromagnesian element, while microcline is absent; quartz is quite subordinate, but sphene rather more abundant. Towards the west over the Nels Hoogte plateau this granite merges into the common or Nelspruit type. The former is appropriately described as an amphibole granite, but may approach a hornblende syenite in composition. The following table brings out the essential characters of the two varieties:

	Nelspruit Type	De Kaap Valley Type
Description	Granitite	Amphibole Granite
Colour	Greyish-white	White or pale greenish
Structure	Massive to Gneissic	Massive in centre, faintly Gneissic along margins
Orthoclase	Present	Present
Plagioclase	Scarce	Scarce
Microcline	Abundant	Absent
Quartz	Abundant	Less abundant
Biotite	Constant and abundant	Absent
Hornblende	Rare	Constant and abundant
Sphene	Very little	Rather more
Pegmatites	Common	Rare
Distribution	Wide	De Kaap Valley only
Relationship	Intrusive	Intrusive

It has been suggested[1] that the De Kaap valley granite is a variety of the Older Granite modified in composition by the submergence in it, of basic rocks belonging to the Jamestown Series, followed by their assimilation.

Throughout the De Kaap and Komati River valleys the Older Granite formation is traversed by a great number of younger basic intrusions—more often as dykes than sheets, of post-Transvaal but pre-Karroo age. They commonly stand out as straight ridges, up to 200 feet (61 m) high and traceable up to 17 miles (27.3 km), the majority conforming to an alignment from south-east to north-west, but several following a direction almost at right angles—south-west to north-east; their thickness ranges from 10 to 200 feet (3 to 61 m). The great majority belong to the dolerite and gabbro families, but one example of an amphibole peridotite is included. Normally these dykes are light greyish green or dark green evenly medium to fine grained massive rocks with plagioclase and pyroxene as essential constituents; locally there is quartz, probably derived as xenocrysts from the granite, against which there are sharp contacts showing selvedge phenomena. The most striking examples are the two powerful parallel dykes which give rise to the conspicuous serrated feature of the Devils Knuckles. Collectively the dykes strongly resemble the basic intrusive sheets of the Pretoria Series, which must be regarded as the sill phase of the basic margin of the Bushveld Complex (see below), so that the dykes probably represent the feeding channels of sills intruded into the Transvaal System during its former extension eastwards over what is now the De Kaap Valley.

Endomorphic modifications of the granite are shown by progressive changes near contacts with older formations, e. g. south-west of the Hectorspruit, by the gradual development of banding etc.; the intrusive relationship is shown by apophyses, contact metamorphism, intrusive transgression, etc. (see above).

The Older Granite continues from the Barberton area for many miles northwards though here and there interrupted by belts of schists and other rocks of the Swaziland System, such as the Murchison Range or the Mount Maré belt (see above); most

[1] Hall, A. L. "The Geology of the Barberton Gold Mining District"—Memoir No. 9, Geological Survey, Un. of. S. Africa, Pretoria, 1918.

of this stretch belongs to the Low Country of the Eastern Transvaal. In the Leydsdorp area there is the usual intimate association between granite and gneiss with a gradual transition from one into the other; the commonest type of granite is a coarse to medium grained greyish rock with a composition very much like that of the Nelspruit type, while the structure is typically granitic without signs of mechanical deformation. Under Low Country conditions mechanical weathering predominates and leads to conspicuous rounded forms of weathering, but nearer the foot of the Drakensberg (e. g. Agatha, Haenertsburg, Tzaneen) chemical disintegration is strong and the granite is converted into red sandy soil down to great depths. Pink varieties are occasionally seen.

Gneissic granite and gneisses are common and widespread throughout the Low Country, specially along the northern side of the Olifants River. Banding is often well marked and uniform, and sometimes so pronounced as to give the appearance of a well laminated sandstone; it is straight and regular, individual bands usually averaging a quarter of an inch in width, and maintained for several yards along their strike. The latter coincides in direction with the schistosity of the Murchison Range, i. e. with the principal tectonic line of the surrounding country, east-north-east to west-south-west and north-east to south-west. Typically the gneisses are silvery grey well oriented rocks, with a mineralogical composition very similar to that of the granite. The lighter coloured bands consist of orthoclase and quartz, while in the darker bands mica predominates, arranged in well oriented layers of biotite. Both gneissic granite and gneiss are invaded by many pegmatites both along and across the planes of gneissic structure. Such pegmatites occur all over the Low Country, and are very abundant e. g. between the Murchison Range and the Olifants River in the south, where they are characteristic of the Mica Fields. They are very coarse associations of pure white quartz and dull white albite or microcline and up to several hundred yards long and up to 100 feet (30.5 m) in width. The minerals making up these pegmatites are often found in masses measuring many cubic yards in volume (Marble Baths) and are accompanied by large pockets of commercial muscovite; locally they also become important through their association with corundum. Normally the pegmatites are fresh brilliant white lenticular bodies showing no foliated structure. Apatite, garnet, tourmaline and iron spinel are occasionally found in them.

Further north, the Older Granite, where the Drakensberg Escarpment has come to an end, continues from the Low Country westwards across a deeply dissected transition belt into the extensive plateau-like country reaching from Pietersburg to the foot of the Zoutpansberg[1]. Over this area the granite-gneiss formation assumes some economic importance owing to its association with many scattered occurrences of basic rocks, the interaction of which with granitic apophyses has led through desilication to the formation of alumina-rich bodies; the latter often carry corundum exploited industrially (see Economic Geology p. 211). In the Bandolier Kop area including the Transition Belt—which connects the Plateau with the Low Country region—the Older Granite formation ranges from massive light coloured even-grained granite to dark coarsely banded gneiss; the massive phase often stands out in isolated rounded masses or clusters of hummocky hills above the general level of the surrounding gneissic country (Matock's Location, Machabas Kopjes, etc.). Such typical "Ball" granite outcrops may be slightly later in age and intrusive into the dark coloured gneisses. The direction of banding is sensibly east and west.

The gneisses are medium to coarse grained and vary from grayish white through dark bluish grey to almost black; some forms are almost massive, but the gneissic

[1] It also continues from the north side of the Zoutpansberg Ranges northwards across the Limpopo River into Southern Rhodesia.

structure is always still traceable in larger outcrops. The composition is:—Quartz, felspar, biotite, pyroxene, with often abundant red garnet, both scattered and arranged in linear fashion. The term garnetiferous pyroxene gneiss often holds good. East of the Pietersburg-Messina railway the gneisses include very coarse and thoroughly dark rocks containing large pyroxenes and conspicuous masses of red garnet.

The massive granites within the Plateau region embrace light coloured pale pink or grey highly acid rocks, poor in dark elements; these rocks are collectively quite distinct from the dark coloured gneisses and it is probable that the original magma of the latter was modified by the absorption of material derived from the many masses of earlier basic groups into which the magma was intruded; the massive granites themselves are most likely later in age than the gneisses. The following table summarises the distinctive characters of the two groups:—

Comparison of Gneisses with Granites.
(Northern and North-Eastern Transvaal).

	Gneiss.	Granite
Structure	Banded	Massive
Grain	Coarse to medium	Medium to fine
Colour	Dark grayish, bluish, or nearly black, dark greenish	Light grey or pink
Distribution	Continuous over large areas	Smaller detached masses
Effect in Scenery	Slight, except over transition belt	Conspicuous hummocky kopjes
Quartz	Fairly common	Abundant
Orthoclase	Rare	Abundant
Plagioclase	Common	Rare
Enstatite	Characteristic	Absent
Monoclinic Pyroxene	Absent or Rare	Occasionally
Biotite	Common	Common.
Garnet	Abundant	Very rare or nil
Corundum	Occasionally	Absent
Apatite	Nil.	Common
Sphene	Nil	Common
Magnetite	Little	Little

The term Palabora Plutonic Complex is applied to a group of massive plutonic rocks, situated in the Low Country between the Murchison Range and the Olifants River, but not yet encountered elsewhere. The complex covers an area of some 250 square miles (647.5 qkm), composed of a series of differentiation products derived from a common magma, later in age and intrusive in the Older Granite-Gneiss formation. The main outcrop forms an elongated wedge-shaped section of country reaching from the junction of the Macoutsi and Olifants Rivers north-eastwards to beyond Palabora, and including the Mashishimala Hills, composed of massive "ball" granite. Outside the main mass several small occurrences indicate the underground extension of the principal mass of the Complex. The bulk of the Complex is an evenly medium- to fine-grained light coloured rock, with a tendency to a porphyritic structure and faintly pinkish colour due to orthoclase. Less acid phases include augite syenite, quartz augite syenite, augite syenite porphyries, etc. In these quartz is very much reduced, pyroxene is plentiful, while orthoclase occurs often in large pale pink zonal crystals. The dominant femic element is deep green diopside-malacolite. The reddish or mottled green syenites pass into dark, often deep green, pyroxenites. Exceptionally there are calcite bearing pyroxenites (Palabora)[1].

In the Central Transvaal the Older Granite formation is represented by

[1] These recall some of the calcite-bearing rocks (e. g. hollaite-pegmatite) recently described by W. C. Brögger from the Fengebiet in Norway.

the Pretoria-Johannesburg granite, occupying an oval stretch of rolling country some 300 square miles (777 qkm) in extent, over which the granite is exposed in boulder-like masses or in small but conspicuous kopjes formed of huge blocks. The typical granite (Half-Way House) is a coarse pale pinkish grey rock with large flesh-coloured felspars: it consists mainly of a rather coarse aggregate of microcline, plagioclase and quartz, together with a little—in part chloritised—biotite and a very little green hornblende; muscovite is very rare. Locally the normal rock is intimately interbanded with fine-grained dark varieties rich in biotite. Variations with dioritic affinities and in the direction of hornblende development are specially characteristic of the south-western border of the area, where the normal rock passes gradually into quartz-diorite and diorite, and becomes foliated; such phases consist of plagioclase, quartz, green hornblende, with usually some biotite, sphene and secondary epidote. Foliated and crushed granite of the acid type occurs along lines, which traverse the central and marginal portions of the mass; these lines have a general north and south trend with ridge-like features often continuous for considerable distances. They are reefs of massive vein-quartz in their central portion, while commonly flanked on either side by a narrow zone of crushed and highly sheared vein-quartz and granite, both kinds of rocks being often brecciated and crushed together; the central portion has also been frequently fractured and brecciated and the fragments re-cemented by secondary siliceous material. One such crush line extends for 12 miles (22 km) and apparently coincides with a line of fault affecting the Lower Witwatersrand System. These crush lines represent large quartz reefs which traversed the granite before it had been much affected by dynamic movements. Subsequent pressure caused brecciation of the reefs with differential movements resulting in crushing and shearing of the flanking rocks.

In the most northerly portion of the Orange Free State, but in part extending across the Vaal River into the southern Transvaal, the Vredefort Granite forms an almost circular outcrop some 25 miles (40 km) in diameter and probablyalso belonging to the Older Granite formation; about one quarter of the circle is still concealed by a covering of Karroo rocks. The Vredefort granite is sometimes massive, but often passes into a streaky or gneissic variety. Normally it is a coarse to medium grained, sometimes light grey, sometimes reddish, rock with a markedly porphyritic appearance, due to large crystals of orthoclase, set in a matrix of plagioclase (oligoclase) and quartz; microcline is rare. Femic elements are not abundant and are represented by biotite, locally accompanied by muscovite. In many places the Vredefort granite is somewhat gneissic and may pass into an ortho-gneiss. Pegmatites are frequent and consist of pale to bright red orthoclase, quartz and mica; the latter often is muscovite. No regularity exists in the distribution of these pegmatites. The granite has been subjected to great pressure, shown by pronounced cataclastic structures, and the great abundance of flinty crush rocks, but its gneissic structure is not due to such pressure, but to movement prior to consolidation. The abnormal composition of the granite (compared with the usual Older Granite, e. g. of the Nelspruit type) is probably due to its peculiar geological history, leading perhaps to a form of migmatic rock[1].

Throughout the Vredefort granite area there are very many occurrences of hard dark-coloured (almost black) flinty looking crush rocks in complex narrow veins —so-called pseudotachylyte, also found in all the surrounding sediments, with the exception of the Karroo rocks; thicker veins of these crush rocks always carry abundant xenoliths of the formations traversed; this peculiar formation is compar-

[1] A. L. HALL and G. A. F. MOLENGRAAFF: "The Vredefort Mountain Land in the Southern Transvaal and the Northern Orange Free State." Verh. Kon. Akad. Wet. 24, No. 3, Amsterdam 1925.

able to the flinty crush rocks described from the Outer Hebrides[1], etc. Although the Vredefort Granite is surrounded by a girdle of Witwatersrand and other sediments, overtilted through many thousand feet of thickness, and intensely metamorphosed up to their contact with the granite, the latter is not instrusive (see section 5 under alkali rocks, p. 111).

In Natal and Zululand the Older Granite formation forms several inliers which probably represent the southerly extension of the large area occupied by that formation in the Eastern Transvaal, but exposed in detached outcrops owing to the partial removal of younger formations, e. g. the Table Mountain Sandstone and the Karroo System. There are two principal inliers; one lies more to the north and extends from Maritzburg in a general north-north-westerly direction across the districts of Krantzkop, Eshowe, N'Kandhla and Vryheid (thus occupying parts of the Tugela River Valley). The other lies south of Maritzburg near the coast and stretches across the Umzinto and Port Shepstone districts, southwards to the mouth of the Umtamvuma River. As in the more northerly parts of the Union, the formation in Natal and Zululand consists of massive granite, gneissic granite, and gneiss, and is closely associated with many small occurrences of basic schists, serpentines, talcose rocks, etc.; the granite gradually passes into gneiss. The former is coarse grained and consists mainly of quartz, orthoclase and mica, more often biotite than muscovite; the colour of the felspar varies from pure white through pink to light reddish brown. The gneisses, e. g. in the Port Shepstone area, are greyish-white to pinkish coarse-grained rocks with large white or pink porphyritic crystals of felspar, and biotite, sometimes accompanied by hornblende. They form streaks and belts of banded gneiss, in which amphibolitic phases are commonly found close to limestone contacts. In other varieties microcline is the dominant felspar. Quartz-veins and pegmatites are abundant in the gneisses and vary from a few inches to a few feet, essentially built up of orthoclase and quartz with locally nests of muscovite; here and there they also carry garnet.

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E. The Pre-Nama Granites and Gneiss of the Cape Province.

By

A. W. Rogers.

So far as is yet known the pre-Nama granitic rocks are confined to the country north of the Karroo and north of the Olifants River on the west coast, but the age of the pre-Cape sediments in the districts of Mossel Bay and George is not known;

[1] Jehu, J. T. and Craig, R. M. "Geology of the Outer Hebrides." Trans. Roy. Soc. Edinb. 53 1923, pp. 419—441, and 53, 1925, pp. 615—641.

though generally called Malmesbury beds, they may be pre-Nama and the granite and gneiss intrusions in them may also be pre-Nama. The alteration of the sediments is much more intense than that of the Nama formation in the Cape and Malmesbury districts.

The greatest area of ancient granitic rocks in the Cape Province is in the north-west, stretching from the Van Rhyns Dorp district through Namaqualand and Kenhardt into Gordonia and Prieska. There is great variety in this mass owing to the presence of sillimanite, garnet, cordierite and other minerals in many parts, but the commonest rock is probably biotite gneiss in which there is much orthoclase, microcline and perthite. Porphyritic orthoclase is often conspicuous, and there are thick and thin layers of pale granulite. Near Steinkopf a certain band of gneiss without quartz is made of much microcline and biotite, little orthoclase and numerous anhedra of corundum; this rock encloses stout crystals of corundum up to eight inches long with a thin coating of granular microcline. Pegmatites are widely distributed. Some in Kenhardt are remarkable for the great size of the microcline individuals, which exhibit cleavage faces many feet across. Near Steinkopf beryl, spodumene, albite, lithia-mica, columbite and tantalite are constituents of the pegmatites.

The foliation strike is often fairly constant within a given region; on the north-west coast belt it is about N.N.W., but in the copper-mining area and southwards to Van Rhyns Dorp it is nearly east and west. In Kenhardt, Prieska and Gordonia the direction is generally about N.N.W. Though large masses of granite without foliation are rare in ancient gneiss, the foliation does not inhibit the development of great curved surfaces, which are a usual feature in the districts occupied by it; they are especially conspicuous in Kamiesberg and in many hills (often of the Inselberg type) in Kenhardt, Prieska and Gordonia. The granite-gneiss of Bechuanaland is of much the same general character as that of the north-west.

In Namaqualand there are almost certainly two distinct gneisses of pre-Nama age; one is older than the Stinkfontein-Kaigas-Numees succession, for boulders of it are found in the Numees tillite and in the Port Nolloth beds of uncertain age but probably not younger than the Stinkfontein series. Some of these beds show profound metamorphism, with the development of garnet and staurolite, at the contacts with gneiss. This later gneiss may possibly be of post-Nama age, but in view of the different type of metamorphism seen at the contact of the Malmesbury beds with the granite-gneiss of the Mord Verloren hills and the neighbouring coast of Van Rhyn's Dorp that is improbable.

The great mass of the Kuboos granite, an unfoliated granodiorite rather than a normal granite, traverses the ancient gneiss and the Stinkfontein-Kaigas-Numees-Groot Derm beds. The contact metamorphism induced in the slates traversed is very like that round the post-Nama granite of the Cape and Malmesbury districts. The age of the Kuboos granite is unknown; it may be post-Nama. It is accompanied by a series of thin dykes of bostonite and camptonite, though whether these were genetically connected with it is not known.

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— see also ROGERS, A. W.

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F. The Norites and Related Rocks of Namaqualand.

By A. W. Rogers.

More than 340 intrusions of these rocks have been mapped in a part (about 1000 square miles = 2590 qkm) of Namaqualand round the copper mines. Some of them appear within a domeshaped structure revealed by the foliation dip of ortho- and paragneis, but the presence of the majority in other situations and the absence of similar intrusions in analogous structures in Namaqualand negative the supposition that the parent magma was connected in origin with the folding of the gneiss, though the crowding of intrusions in a limited area indicates the proximity of that magma to what has become the surface there. Owing to the presence of copper-iron sulphides in almost all the intrusions and their abundance in some of them the name ore-bearer is used to cover the several varieties which occur in masses large enough to be considered as petrological units. The chief component minerals other than sulphides are hypersthene, augite, biotite, hornblende, plagioclase, quartz, apatite, green spinel, magnetite, hematite, and zircon; potash felspar is very rarely found and olivine has not been seen in these rocks, which range in composition from monomineralic rocks made almost wholly of hypersthene, biotite, plagioclase or quartz, to mica-diorite and norite; in one instance a granite is apparently part of an intrusion, and in another aegirine-augite is abundant. In many intrusions magnetite and sulphides are conspicuous, the sulphides being chiefly bornite, chalcopyrite and pyrrhotite.

Copper sulphides in sufficient abundance to make the rock worth mining under local conditions (i. e. 4% or more of metallic copper) occur in some of the bodies of mica-diorite, norite and hypersthenite. An individual intrusion usually consists of more than one variety of rock; no fine-grained margin has been observed at the limit of an intrusion or at that of one of the component bodies. The intrusions are rather irregularly shaped dykes, pipes or roughly columnar bodies up to 1000 feet (305 m) wide, and nearly horizontal masses of small extent connected with highly inclined bodies. The shapes of the several component bodies of one intrusion are irregular in the columnar intrusions but conform roughly to the greater dimensions of the dykes and sheets. The impression conveyed by a study of the mines, prospecting works and outcrops is that the several varieties of rock were represented immediately before intrusion by as many differentiates of the parent magma lying in close proximity, and that the conditions of intrusion did not permit mixture or diffusion on a considerable scale, the several derived magmatic bodies being drawn out in shapes conditioned by the form of the space in which the composite body became solid. In several instances orbicular bodies with radial and concentric arrangement of the plagioclase and magnesian silicates occur in the norite and mica-diorite. The distribution of the sulphides is like that of the silicates; in any one intrusion one variety of rock, say hypersthenite, persistently has more or less sulphides in it than norite, though in another intrusion the norite may be the richer in sulphides. The sulphides appear to have been constituents of the differentiated magmas and they, together with most of the oxide of iron solidified at a late stage, after the silicates, which are to some extent replaced by them. Migration of sulphides from the ore-bearer to the rocks enclosing, or enclosed by, them has taken place, though not to an extent sufficient to give those rocks economic importance.

The date of the intrusion of the ore-bearer was almost certainly pre-Nama.

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2. The Witwatersrand System.

By A. W. Rogers.

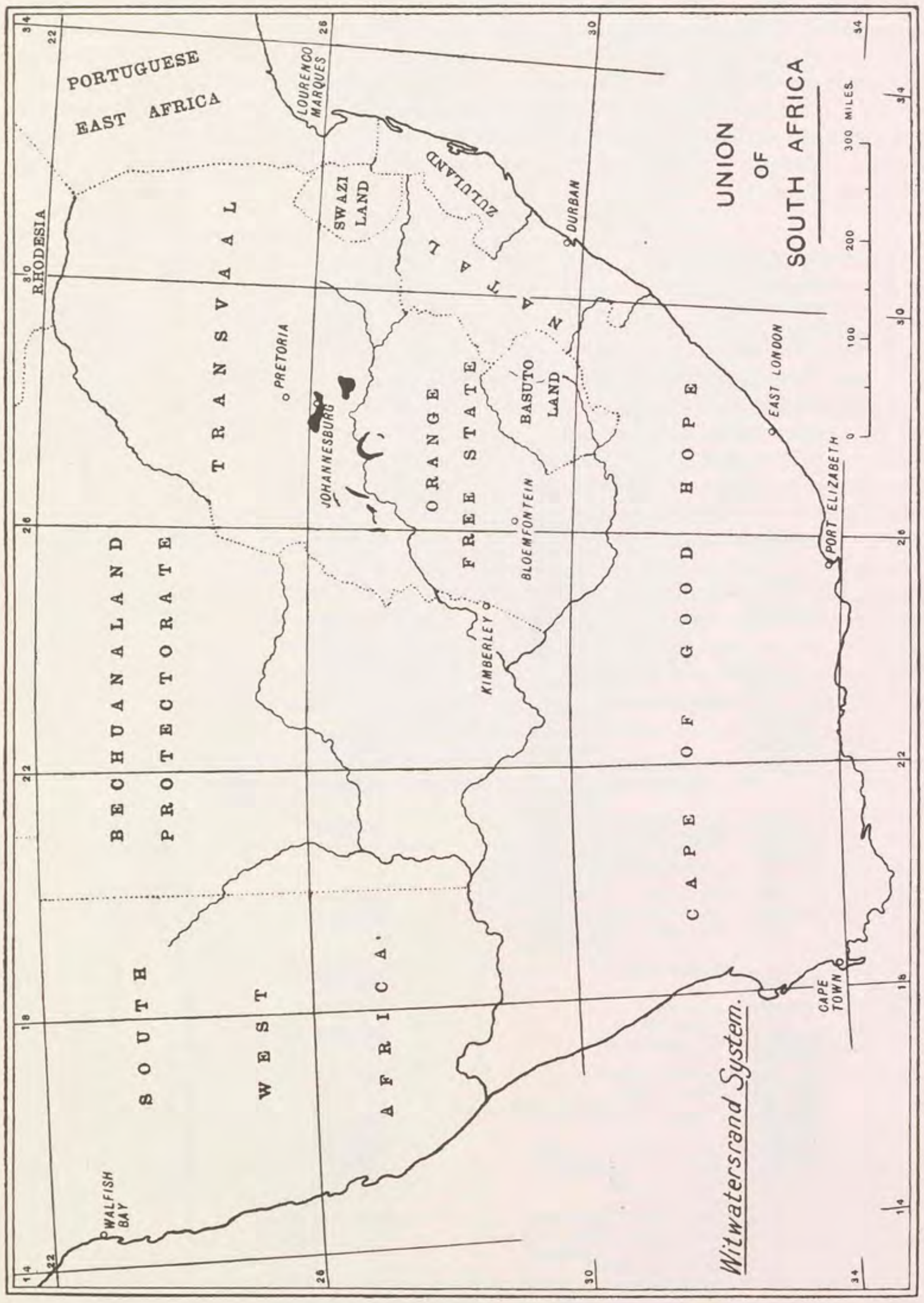

Fig. 15. Outline Map showing the distribution of the Witwatersrand System.

The Witwatersrand beds occur as inliers, either alone or associated with the older granite or with the younger Ventersdorp beds, surrounded by rocks belonging to the Transvaal and Karroo formations in the southern Transvaal and the northern part of the Orange Free State. The chief areas (see Fig. 15) are those of the Witwatersrand, Heidelberg, Parys and Klerksdorp. In Klerksdorp, where the detailed survey of the formation has not yet been completed, there is difficulty in delimitating the subdivisions above the Government Reef series as established further east both on account of a stratigraphical break and faulting of later date. East of Klerksdorp the sub-divisions established by E. T. Mellor on the Rand are recognised with certainty by their lithological characters and succession, and their variations in thickness have been observed:—

	Heidelberg		Witwatersrand		Parys	
	feet	m	feet	m	feet	m
Kimberley-Elsburg Series . .	3700	1128	6000	1828	10500—15000	3200—4572
Main-Bird Series	1000	305	3000	914	2000— 3400	610—1036
Jeppestown Series	1800	549	3500	1067	1500— 1700	457— 518
Government Reef Series . . .	4049	1234	6220	1896	5060— 6100	1542—1859
Hospital Hill Series	3179	969	4815	1468	3200— 3900	975—1189

The Witwatersrand and Ventersdorp beds are closely connected; the volcanic activity which gave rise to the great outpouring of Ventersdorp lavas was foreshadowed by several minor volcanic episodes which have left their products interbedded with the Witwatersrand strata in the recognised areas of those rocks. It is known that unconformities exist within both the Ventersdorp and Witwatersrand formations, proving that the region they occupy was one of considerable disturbance throughout a long period. In default of continuity of outcrop and palaeontological evidence, correlation of groups of rocks in separated areas such as Prieska, the Derde Poort range, Klerksdorp and the Witwatersrand, is only possible if the successions preserved in each region are very similar, as they are in the Witwatersrand, Heidelberg, Parys and, in part at least, in Klerksdorp. Many years ago F. H. Hatch suggested that the Witwatersrand and Ventersdorp beds should be placed in one system, and that would probably have been done but for the economic importance of the Witwaters-

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Reference to Fig. 16 „Comparative Sections through the Witwatersrand Beds in the Vredefort and Heidelberg Areas and on the Witwatersrand."

V.A.	Ventersdorp Amygdaloid.	Kimberley-Elsburg Series.	Upper Witwatersrand.
E.R.	Elsburg Reefs.		
K.R.	Kimberley Reefs.		
K.S.	Kimberley Shales.		
B.R.	Bird Reefs.	Main-Bird Series.	
B.A.	Bird Amygdaloid.		
M.R.G.	Main Reef Group.		
V.B.	Volcanic Beds.	Jeppestown Series.	Lower Witwatersrand.
B.G.	Blue Grit.	Government Reef Series.	
D.G.	Dark Grit.		
G.R.	Government Reef.		
T.	Tillite.		
C.R.	Coronation Reef.		
P.R.	Promise Reef.		
F.I.S.	Felspar and granite pebbles in slate.		
H.H.Q.	Hospital Hill Quartzites.	Hospital Hill Series.	
B.G.Q.	Black Grit Quartzites.		
C.B.	Contorted Beds.		
S.B.	Speckled Beds.		
R.M.Q.	Ripple-Marked Quartzites.		
W.T.S.	Water Tower Slates.		
O.G.Q.	Orange Grove Quartzites.		
Bas.A.-	Basal Amygdaloid.		
P.W.R.	Pre-Witwatersrand Rocks.		

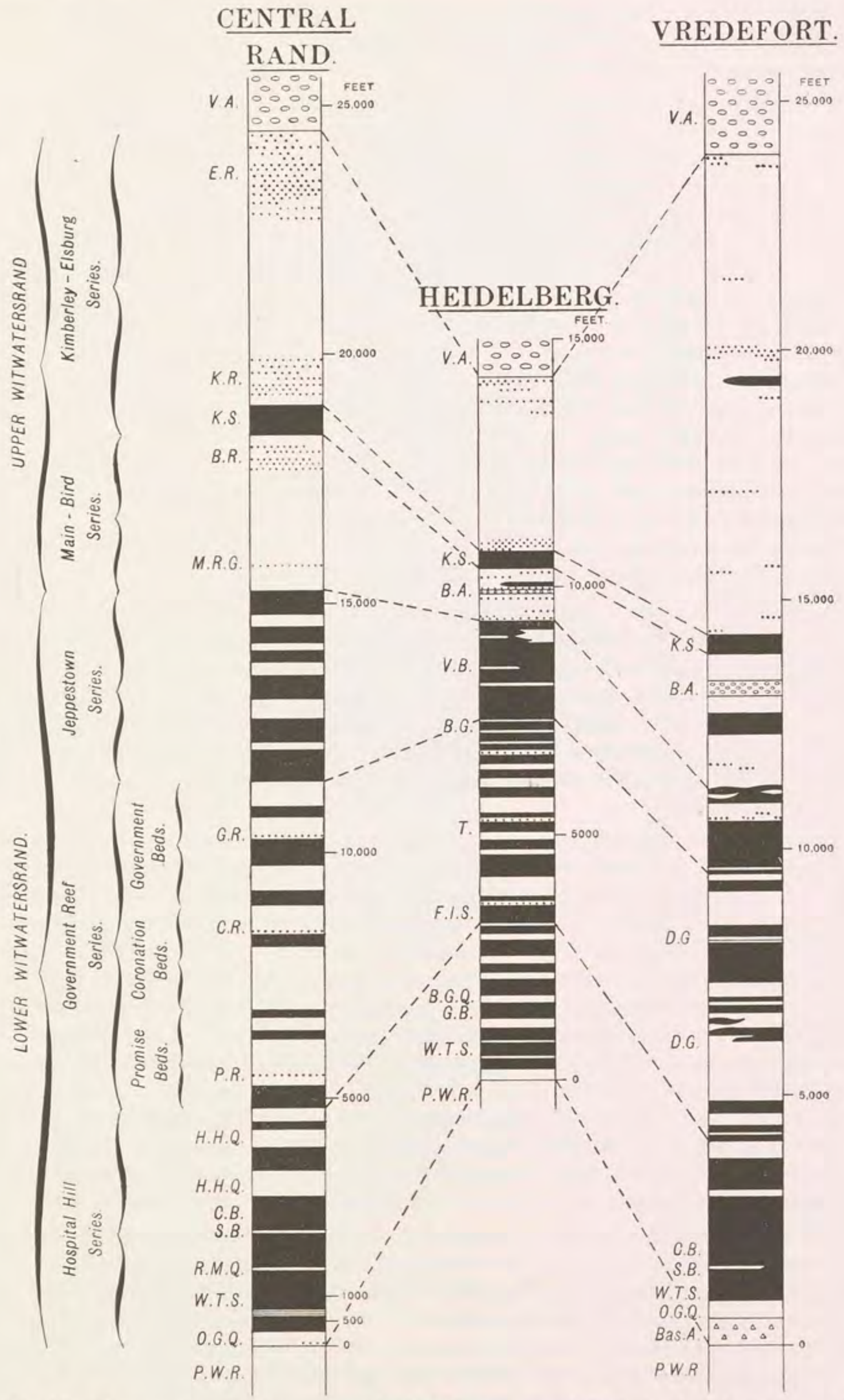

Fig. 16. Comparative Sections through the Witwatersrand Beds in the Vredefort and Heidelberg Areas and on the Witwatersrand.

rand beds. It is possible that Witwatersrand beds are represented by beds included in the Ventersdorp System in the Cape Province, but at present there is no conclusive evidence for the correlation.

The Witwatersrand beds consist of alternations of arenaceous and argillaceous sediments with banded siliceous ironstones and a few intercalations of volcanic rocks; limestones and calcareous shales have not been found amongst them. Fresh felspar is a constituent of some of the quartzites and argillaceous rocks, but owing to microscopical study of the sediments having been almost confined to the auriferous conglomerates, which have undergone alteration through partial redistribution and replacement of their original minerals, detailed information about the constituents of a very large part of the sediments is not yet available. Conglomerates form a minor part of the whole formation, and they vary in abundance in different regions, being most frequent in the central Witwatersrand, where they form about 2000 feet (610 m) of the 25000 feet (7620 m) of sediments, and least conspicuous in the Parys area, where some 200 feet (61 m) of more than 20000 feet (6096 m) of rock are conglomeratic. Though many of the conglomerates are auriferous, persistence and content of gold sufficient to repay the cost of mining and extraction under present economic conditions are confined to a few feet of rock amounting to about 20 feet (6.1 m) in certain areas, and these payable strata are almost restricted to the Main Reef group of conglomerates, comparatively small additions being obtained from the Kimberley Reef group in the West Rand.

In the many papers describing the geology of the Witwatersrand terms are often used in their local acceptation rather than with their proper lithological sense; thus "shales" in the local usage may mean any fine-grained sedimentary rock that is distinctly laminated and not obviously a quartzite, and it is applied to such different rocks as slate, quartz-schists and banded ironstone or jaspillite. There are probably no true sandstones in the formation, but the siliceous cementing material in many of the quartzites disappears in weathering, and the outcrops are often called sandstone.

It is well to remember that the outcrops of the Witwatersrand beds are almost the same surfaces that were subjected to weathering in early Karroo times; and, in certain areas, they had also been exposed to the weather before they were covered by the Black Reef Series. The distribution of thin remnants of the Dolomite and Black Reef series over the West Rand shows that a very large part of the eroded Witwatersrand beds was removed before the deposition of the Black Reef series; though the evidence elsewhere is less obvious, there is little doubt that in the Johannesburg district most of the erosion which reduced the surface of the Witwatersrand formation to its present shape was performed before the Black Reef was laid down. It is possible that the gold in the Black Reef conglomerates was originally alluvial gold from the Witwatersrand beds. That no corresponding deposits of gold have been found in the basal Karroo beds is explained by the history of the denudation above mentioned, which also accounts for the lack of modern alluvial deposits containing gold in the country traversed by the streams draining the Witwatersrand.

The Witwatersrand is on the northern outcrop of beds that form a wide and irregular syncline stretching from the Far East Rand west-south-westwards through the Potchefstroom district (see Fig. 17). The initiation of the northern flank of the syncline took place before the deposition of the Rand beds was completed, for to the north of a line drawn through Johannesburg and Krugersdorp the Ventersdorp beds overlap unconformably the whole of the Rand beds and come to lie on the older granite and schists; the conglomerates of Langerman's Kop and on the north side of the western part of the Observatory ridge, believed to be of Elsburg age, give evidence of unconformable overlap during the later part of the Witwatersrand period. The succession in the Klipriversberg and Heidelberg is unbroken, so very considerable earth movements took place during the deposition of the Upper Witwatersrand beds. The several reversed faults or thrust-planes, of which the Rietfontein and Witpoortje faults are the most important, though probably represented also by the much smaller thrusts duplicating parts of the beds mined in the Central Rand, are of later date than outpouring of at least the earlier Ventersdorp lavas, for the latter are displaced by the great reversed faults, which, however, do not effect the Black Reef series.

Since the Transvaal as well as the Ventersdorp and Witwatersrand formations are involved in the syncline extending through the Potchefstroom district, the syncline was not completed until a correspondingly late period, and the thickness of the rocks affected, volcanic and sedimentary, is very considerable, not less than 40000 feet (12190 m). The southern flank of the syncline has a complicated structure in which there is no evidence of the earlier movements found in the Witwatersrand itself. The inversions about the old granite mass of Parys and, perhaps, the high dips and thrusts near the escarpment of Lower Witwatersrand beds east of Heidelberg were imposed after the deposition of the Transvaal System. The great overlap of the Black Reef over the Ventersdorp beds in both the East and West Rand indicates irregularity of movement in the synclinal area. The normal fault, with a throw of 16000 feet (4877 m) at one place, trending east and west through the Heidelberg district (Sugarbush fault) is almost certainly later than the Dolomite.

There are at least four main groups of intrusive rocks later than the Witwatersrand beds in the southern Transvaal. The earliest of these form very numerous thin dykes and sheets which are rarely seen in outcrops, but are frequently cut in the mines. They are fine-grained, much altered rocks of intermediate composition; they have been broken and sheared, displaced by the earliest faults affecting the Rand beds, and ottrelite has been developed in many of them. The second group of intrusions are pyroxenites, norites, dolerites and quartz-dolerites of post-Ventersdorp age, which, in Heidelberg, are of later date than th eminor faults but earlier than the Sugarbush fault.

The third group comprises the extensive sheet often called syenite (quartz-augite-diorite) penetrated by several of the shafts in the Far East

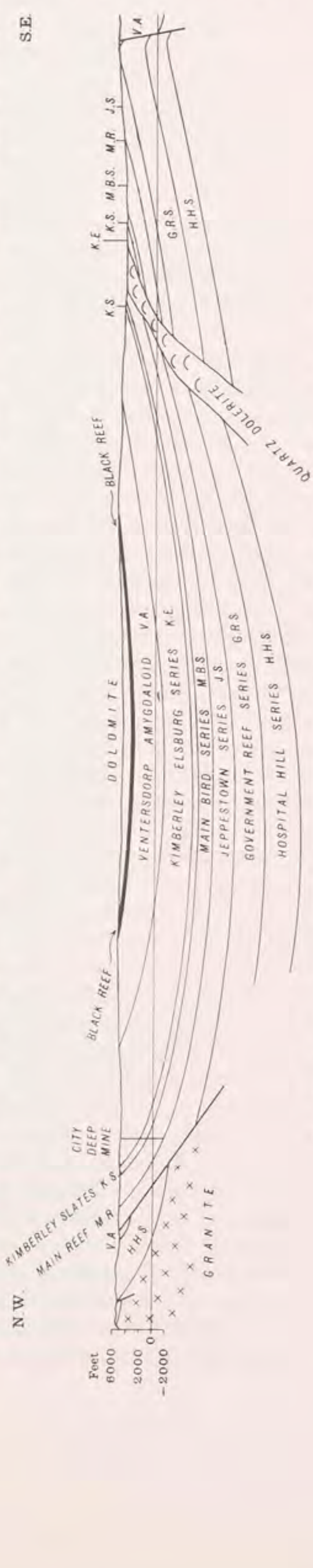

Fig. 17. Section across the Witwatersrand Beds through the City Deep Mine, Johannesburg.

Rand, many dykes of related types, and elaeolite-syenite, solvsbergite and quartz-keratophyre. These are no doubt related in origin to the soda-rich rocks of the Bushveld region. The fourth group is the dolerite of late-Karroo age, dykes of which are rarely seen in the Rand or other pre-Karroo rocks, but sheets occur at or near the base of the Karroo sediments overlying the Rand and Ventersdorp beds.

The Hospital Hill Series is the name given to the lowest of the larger subdivisions of the Lower Witwatersrand beds owing to its forming the ridge of that name immediately north of Johannesburg. The escarpment overlooking the granite and schists to the north is made of the basal beds, the Orange Grove quartzites, in all some 350 feet (107 m) thick separated into three bands by originally argillaceous, but now micaceous and schistose rock. In the escarpment overlooking the High Veld east of Heidelberg, the Orange Grove quartzites are thinner than on the Rand, and east of Nigel this escarpment gradually disappears, the beds having been cut off flat with the granite in pre-Karroo times. In the Vredefort Mountain Land the Orange Grove beds are at least as thick as they are north of Johannesburg. The Orange Grove quartzites are generally thoroughly quartzitic and white at the outcrop; pebbles are often found at the base, where the rock rests on a denuded surface of granite or schists, except in the Vredefort area, where a band of amygdaloidal lava (now altered to pyroxene granulite) some 500 feet (152 m) thick, intervenes between the granite and the Orange Grove quartzite.

The Orange Grove quartzites are followed by the Watertower slates [800 feet (= 244 m) thick on the Rand] which are ferruginous slates with a few subordinate beds of quartzite. A conspicuous feature is a band of heavy magnetic rock, often thinly bedded and occasionally with thin intercalations of pale cherty rock. These beds, including the magnetic rock, are also found in Heidelberg and Vredefort. On the Witwatersrand a conspicuous group of rippled quartzites about 20 feet (6,1 m) thick overlies the Watertower slates, and they are called the Ripple Marked Quartzites, but they have not been identified in Heidelberg or Vredefort, where there are two more bands of quartzite in about the same stratigraphical position.

The red-weathering slates overlying the Ripple Marked Quartzites on the Rand include some 1400 feet (427 m) of rock of which about half are hard, ferruginous and thinly bedded, with a portion made up of pale cherty rock interbedded with highly magnetic layers. These banded rocks are often much contorted though the beds immediately above and below them are in a normal condition; they are called The Contorted Beds. The Speckled Bed is a rather coarse grained felspathic rock about five feet thick lying just below the Contorted Beds; the felspar grains provide striking instances of secondary enlargement by the deposition of felspar in continuity with that of the detrital grains. Rocks similar to the Contorted Beds occur elsewhere in the Witwatersrand succession, especially in the Watertower slates and the West Rand or Coronation Slates. In Heidelberg the Speckled Bed has not been identified, but the Contorted Beds are well developed. In the Vredefort region both are found, the Speckled Bed being thicker there than on the Rand.

On the Rand and in other districts where the Lower Witwatersrand beds occur, very prominent outcrops are often formed by the Hospital Hill Quartzites, to which belong quartzites seen in dip-slopes immediately north of Johannesburg. There are three thick groups of these quartzites on the Witwatersrand, and the two upper groups contain lenses of unusual character, having large spherical grains of quartz set in a matrix of much smaller angular or subangular grains (sago-structure). The Hospital Hill quartzites frequently have a green micaceous mineral in them, but neither the green tint thus given them nor the sago-structure is peculiar to the series. In Heidelberg there is a prominent quartzite with small black chert pebbles, the Black Grit Quartzites, in this group.

The succeeding **Government Reef Series** is a quartzitic and argillaceous group in which the quartzites are less purely arenaceous than those in the Hospital Hill Series, and alternations of arenaceous and argillaceous beds are frequent. Thin conglomerates occur chiefly on three horizons and have been called the Promise, Coronation and the Government reefs, in upward order. In addition to these a boulder bed having the character of a tillite lies immediately below the ferruginous thinly banded West Rand or Coronation Slates below the Coronation Reef in Heidelberg, and also in Klerksdorp, but on the Rand the boulders on that horizon have not been found to be striated. This is one of the oldest of the five horizons on which evidence of glacial action has been found in South Africa. Immediately below the uppermost quartzite of the Government Reef Series in Heidelberg, there is a peculiar grit (Blue grit) rarely laminated, containing much fresh felspar, quartz, chert and limestone in angular fragments; it reaches a thickness of 750 feet (229 m) in Heidelberg, but it has not been recognised on the Rand or in the Vredefort and Klerksdorp inliers.

The **Jeppestown Series** is mainly an argillaceous group with subordinate beds of quartzite, usually argillaceous, and volcanic breccias, tuffs and lavas in Heidelberg; on the Rand lava is interbedded with the slates south of Krugersdorp, and the lavas struck in a bore-hole on Palmietkuil may be in this series. The Jeppestown beds on the Rand and in Heidelberg have suffered much deformation through faulting, and the outcrop varies greatly in width within short distances. They are comparatively weak rocks lying between the more arenaceous Government Reef Series below and the still stronger and more uniformly arenaceous Upper Witwatersrand beds above, so the stresses accompanying the formation of the Rand-Heidelberg syncline appear to have found more relief in deforming the 3000 feet (914 m) of weak Jeppestown rocks than the stronger und and overlying beds. Owing to the comparatively soft character of the beds, they are usually concealed by soil, and are less well known than the other subdivisions of the system.

The divisional plane between the Lower and Upper Witwatersrand beds is drawn at the base of the quartzites below the Main Reef group of conglomerates, and as the quartzites below and immediately above the Main Reef itself pass eastwards into slates, the Lower limit of the group is drawn at the base of the remaining quartzites, which happens to be the base of the Main Reef Leader, in the Far East Rand and Heidelberg. In the Western, Central and near East Rand the basal beds below the Main Reef are quartzites and grits with a few inconstant beds of pebbles as well as grits with pebbles scattered through them. The thickness of those beds is at most about 600 feet (183 m). Towards the east they give place to argillaceous rocks, though quartzites occasionally reappear.

The **Main-Bird Series** includes the beds up to the base of the Kimberley slates. The Main Reef group of conglomerates contains several individual beds of conglomerate and is in the lower part of the series, and, in the East and Far East Rand, as explained above, it forms the actual base. The Main Reef is the name given to the lowest conglomerate which has been, and is being, mined on a large scale on the Rand. It is from 3 to 10 feet (0.9—3 m) thick and is often divided into two or three parts by lenses of quartzite. The pebbles are generally small and unsorted, in contrast with the average decrease in size upwards of the pebbles of the Main Reef Leader above. The Main Reef is developed in the West, Central and near East Rand, disappearing in the Cason mine. In the western part of the Central Rand a bed called the Main Reef Leader becomes distinguishable from the Main Reef on which it at first lies directly and, followed eastwards, is separated from by quartzite and dark argillaceous quartzite called Black Bar, in which much chloritoid has been developed. The Leader persists through the Central, East and Far East Rand, and is now the chief source of the ore. Towards the east it becomes a series of "elongated, discontinuous lenses radiating in plan to the east and south-east of Benoni" (L. Reinecke). The Leader ranges in thickness up to about 9 feet (2,7 m), but the thicker portions include lenses of quartzite. In places the conglomerate fills channels eroded in the footwall. The Leader dwindles to a grit in the Heidelberg district, though in the Nigel area (the Nigel Reef) and for a few miles to the south-west it is still a conglomerate. The Main Reef group of conglomerates has not been recognised in the Venterskroon and Klerksdorp regions. In the Central, Western and near East Rand a third body of conglomerates, known as the South Reef, up to 10 feet (3 m) thick lies above the Leader; in the Central Rand it lies from 70 (21 m) to 110 feet (33.5 m) above but is in contact with the Leader in places towards the east. In certain mines of the Far East Rand there are conglomerates known as hanging-wall leaders above the Main Reef Leader. They are much less extensively developed than the Leader, but they may be important additions to the known available ore.

The pebbles in these conglomerates are mostly of quartz, banded or uniform chert, quartzite, slaty rocks and quartz-porphyry in which the felspar is replaced by quartz and sericite. The common authigenic minerals are quartz, sericite, chlorite, chloritoid, pyrites (about 3% of the rock), rutile, tourmaline, a form of carbon, and gold, almost all of which were probably derived from materials in the sediments when deposited. Diamond occurs as an original component.

The Main Reef group is overlain by quartzites, up to 3000 ft. (914 m) thick in the Central Rand, including several layers of pebble beds, the Livingstone and Bird Reefs. In the East and Far East Rand and Heidelberg there is a volcanic group, the Bird Amygdaloid, interbedded with these quartzites. The volcanic rocks are much altered but were probably andesites; the precise nature of the original constituents is uncertain, though in part of Heidelberg albite-oligoclase, andesine, and bastite pseudomorphs after rhombic pyroxene have been determined. On certain mines dark detrital layers as well as quartzite are intercalated with the lava, while to the west of Boksburg dark sediments (Bird Reef Marker) consisting of chlorite, sericite, chloritoid and quartz grains occur on the horizon of the volcanic rocks. No volcanic breccia has been found associated with the lava in the Witwatersrand area, but it occurs in Vredefort at the top of lavas on the same horizon. The maximum thickness of the volcanic group is about 300 ft. It is overlain by a few hundred feet of quartzites which pass up into a thick (600 feet (183 m) on the Central Rand) group of slates (Kimberley Slates or Shales), the bottom of which is taken as the base of the **Kimberley-Elsburg Series**. The top of the Kimberley Slates is well defined. This group of slates is important in locating horizons in boring, for it is the only thick body of argillaceous rocks known in the Upper Witwatersrand beds in the Rand and Heidelberg. The Kimberley slates are followed by arenaceous beds up to 5500 feet (1676 m) thick including two groups of conglomerates, the Kimberley Reefs near the base and the Elsburg Reefs near the top. These conglomerates are, individually, less persistent than those in the Main Reef group, though as groups they have a wider distribution. On the Rand dozens of lenticular beds of conglomerate may be found in one line of section; but in Heidelberg and the Venterskroon area they are much less numerous, though they are better developed than the Main Reef group. In the West Rand some parts of the Kimberley Reefs are mined, but in general their gold content is small and erratic in distribution.

The Kimberley-Elsburg series south of Johannesburg and in Heidelberg passes up into the Ventersdorp formation through a few inches or feet of quartzitic grit, or small pebble conglomerate, in parts of which a dark chloritic matrix takes the place of the pale quartzitic groundmass of the rock immediately below, indicating the advent of volcanic material.

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Maps: Sheet 52 (Transvaal) and the Witwatersrand, Heidelberg and Vredefort maps. Geological Survey, Pretoria.

3. The Ventersdorp System.

By

A. W. ROGERS.

Resting conformably on the Witwatersrand beds south of Johannesburg and in Vredefort is a thick [11000 feet (= 3353 m) in the Venterskroon area] succession of andesitic lavas commonly called the amygdaloidal diabase. North of Klipriversberg this formation overlaps the Witwatersrand beds unconformably, resting on the upturned edges of the Hospital Hill series at Observatory and upon the older granite and schists to the north-east. In Klerksdorp there is an unconformity below quartzites and conglomerates which pass under the lavas, and this unconformity may be a result of the same great overlap. North and west of Klerksdorp the Rand beds are either covered unconformably by, or are not seen between, the Ventersdorp beds and the Old Granite and schists. Sediments make up an important part of the formation in Ventersdorp, Klerksdorp and south-east of Heidelberg (see Fig. 18).

In the south-western Transvaal the amygdaloidal diabase covers a wide area; it extends down the valley of the Vaal into the Prieska district, and westwards into Bechuanaland where it thins out between the Old granite and the Black Reef series. Neither in these regions nor in the neighbourhood of Crocodile Pools and the Witfontein Rand are there rocks that are recognised as Witwatersrand beds, though the latter may be represented in the Cape Province by the lavas and sediments of the Zoetlief and Kuip series which are unconformably overlain by the Pniel amygdaloidal diabase. In the Kenhardt and Gordonia districts a series of conglomerates, sandstones, red quartz-felspar porphyries and basaltic lavas and tuffs lies on the basement schists and has yielded no fragments derived from the Transvaal or Waterberg formations. It is therefore placed in the Ventersdorp System. In the Eastern Transvaal and Natal the Ventersdorp beds have not been recognised. The time represented by the Witwatersrand and Ventersdorp beds was one of considerable earth movements and widespread volcanic activity in the southern and western Transvaal and northern districts of the Cape; elsewhere in the Union there is no evidence yet known bearing on the period. It may be noted here that the type of volcanic activity represented by the Pniel lavas was continued into the period of the Transvaal System, for the lavas interbedded with the Black Reef quartzites and lying above them in the Vryburg district, Mafeking and the immediately neighbouring part of Lichtenburg closely resemble those of the Pniel group, though the Black Reef Series there, as in the southern Transvaal, is separated from the Ventersdorp beds by a marked unconformity.

The **Zoetlief Series** is the name given to acid volcanic rocks and various sediments, chiefly quartzites, lying unconformably below other beds of the Ventersdorp system at several places in and between the Vryburg and Prieska districts. Though it seems certain that they are represented by some part of the Witwatersrand-Ventersdorp succession in the southern Transvaal exact correlation cannot yet be drawn. In the Kimberley Mine shaft the lowest 300 feet (91 m) of the Zoetlief beds are conglomerates and quartzites and these are overlain by 1000 feet (305 m) of rhyolitic lavas with tuffs. The best exposures of the series showing its relation to higher members are in the T'Kuip hills in Prieska, where the conglomerates, arkoses, breccias, rhyolites and quartz-andesites composing it are unconformably overlapped by the **Kuip Series** with amygdaloidal andesitic lava, very like the "diabase" commonly associated with the Ventersdorp System, at the base, followed by arkose, flagstones, limestones and chert above which comes more diabase overlain by flagstones and arkose; the total thickness is not less than 1500 feet (457 m).

The **Pniel Series** consists of amygdaloidal andesites and sedimentary rocks which underlie the Vaal River Valley almost continuously from near its junction with that of the Orange up as far as Klerksdorp, and they form a very large part of the pre-Karroo peneplain which is such a striking feature in the south-western districts of the Transvaal. The succession varies considerably; in the Cape Province sediments, especially quartzites and conglomerates, often occur at the base; at Kimberley they are 700 feet (213 m) thick. Blue andesitic lavas chiefly with amygdales of chalcedony which in places are of a striking red colour, is the most frequent type of rock, but quartz-porphyries occur in the upper part of the series below Barkly West.

In the Transvaal the greatest development of the Ventersdorp system is probably found in the Heidelberg district and in the Vredefort area. As there was apparently continuous deposition of sediments or outpouring of lavas in these areas it may be assumed that the three series differentiated in the Cape Province are represented in the southern Transvaal by the unbroken succession, though a base common to the two regions cannot be pointed out. In Heidelberg south of the Sugarbush Fault the lower 5000 feet (1524 m) or so of the formation is amygdaloidal andesite with minor intercalations of tuff, and above lies a considerable thickness of conglomerates, flagstones and lavas of more acid composition than the blue andesites. In the Klipriversberg, 30 miles (48 km) to the north-west, and in the hills behind the town of Heidelberg half-way between, nothing like the upper and mainly sedimentary group has been found. In Ventersdorp and Klerksdorp coarse conglomerates form a conspicuous part of the lower portion of the formation, while quartz-porphyry, lavas and breccias occur above a considerable thickness of blue amygdaloidal diabase. North-east of the Witwatersrand the basement beds are thick breccias and conglomerates. In the northern part of the Marico and Rustenburg districts the Ventersdorp beds are again seen between the Old Granite and the Black Reef Series. They consist of acid and basic lavas with agglomerates, tuffs, shales and conglomerates. The succession varies much along the hundred miles of outcrop. In this area occurs a quartzitic conglomerate originally placed near the top of the Ventersdorp system; it was found to be auriferous and a detailed survey of the prospecting area made by Dr. Wagner points to the probability of the conglomerate and associated quartzite belonging to the Black Reef Series.

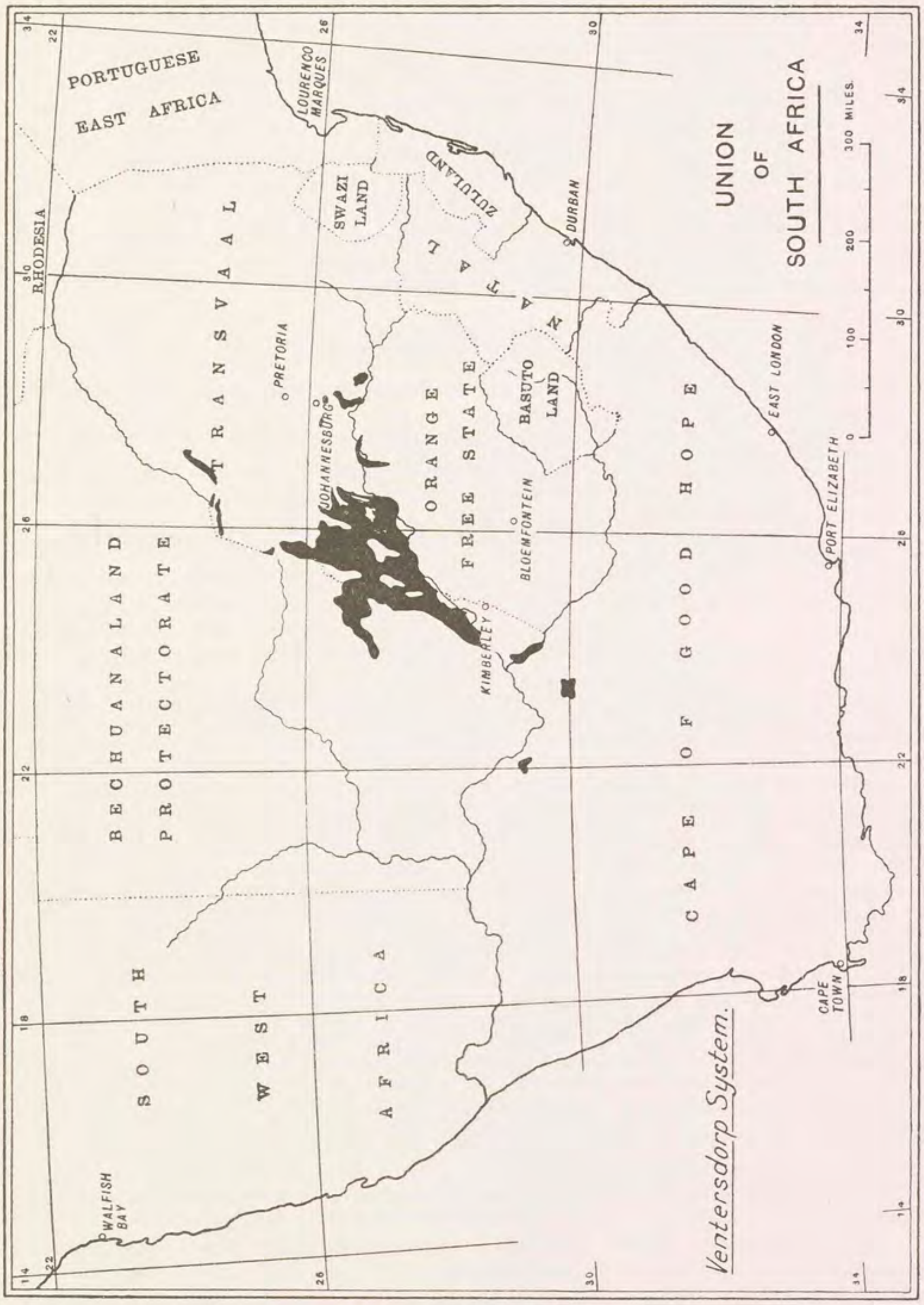

Fig. 18. Outline Map showing the distribution of the Ventersdorp System.

The **Koras Series** consists of quartz-porphyries and amygdaloidal pyroxene andesites differing considerably from the usual volcanic rocks of the Ventersdorp system, and conglomerates and sandstones containing pebbles derived from the Koras igneous rocks as well as from the Swaziland beds and gneiss, but no fragments from the Transvaal or Waterberg formations, nor from the well-known types of Ventersdorp beds, have been found in them. The Koras beds occur in the valley of the Orange River for some 30 miles (48 km), and they are not affected by the shearing undergone by the Swaziland beds, so they are placed in the Ventersdorp system for convenience, although the only other evidence of their age at present known is the occurrence of their characteristic rocks in the Dwyka tillite, proving them to be of pre-Karroo age. The quartz-porphyries often have phenocrysts of orthoclase intergrown with quartz and a red felsitic matrix; the andesites and basaltic rocks are also predominantly red, as are the conglomerates and sandstones.

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Maps: Cape Sheets 33, 40, 41, 42, 46, 50, 52.

Transvaal Sheets: 6, 9, 14, 15, 52. And the Witwatersrand, Heidelberg and Vredefort maps. Geological Survey, Pretoria

Konkip Formation.

In 1915 the writer described four series named in upward succession the Stinkfontein, Kaigas, Numees and Groot Derm series from the north-western part of Namaqualand, the region known as the Richtersveld. They were placed somewhat doubtfully in the Nama System, being regarded as probably the western representatives of that system in a much disturbed condition; though later in age than the great or older mass of Namaqualand gneiss, they were invaded by the Kuboos batholith and also by the "later" gneiss south of the Cape Copper railway. The probable correlation with the Nama was based on the lithological resemblance of the Stinkfontein-Kaigas succession to the Nieuwerust-Malmesbury; and on the presence of certain red limestone boulders in the Numees Tillite, which were believed to have been derived from similar limestones seen in place in the Malmesbury beds of Neint Nababeep. The correlation was also supported by the fact that the Nama beds on the western flank of Neint Nababeep were folded and overturned, an area of the older gneiss 15 miles wide separating them from their supposed western and more altered representatives. Andrew Wyley, who examined the area in 1856, saw the lithological resemblances but was confident that the two groups were very different in age. In 1912 Dr. Range established a varied group of rocks, older than the Nama but younger than the old gneiss of South West Africa, under the name of Konkip Formation, and from Dr. Beetz' work it appeared that the western succession really belongs to this formation, while Dr. Haughton and Mr. Frommurze have found the western series approaching so close to the base of the Nama System north of the Orange River as to remove all doubt that the suggested correlation of the two is wrong; the western beds are much the older. They will be described here under the names given to the series in 1915, but whether the four series are correctly placed in the Ventersdorp System is very doubtful. There is no general resemblance to the Koras series, and little to the more distant but better known Ventersdorp beds.

The structure of the area occupied by the four series in Namaqualand is complicated, but for considerable distances the order of succession of the three first named series is undisturbed and constant, and that order is adopted here as the true one for them.

The **Stinkfontein Series** consists of arkose, thin conglomerates, quartzites, quartz-schists, phyllites and a remarkable band of lavas and tuffs of trachytic and andesitic character. The series forms a belt of country over 100 miles (161 km) long from north to south and nearly 25 (40.23 km) wide in places, though narrow inliers of gneiss may be included in that width. It is repeatedly folded, and in Dunn's mountain may be no more than 700 feet (213 m) thick. Near Modderfontein, however, where the volcanic group is extensively developed, the lavas and tuffs alone are about 600 feet (182 m) thick. The quartzites have much magnetite in them in places, though that mineral occurs in sufficient abundance to give the rocks a dark colour in layers up to 2 inches (5 cm) thick only. The junctions with the presumably older gneiss are much sheared, but at one place there is marked difference in strike between the gneiss and basal schists of the Stinkfontein beds. South of Port Nolloth and again south of the Buffels River the Stinkfontein beds are invaded by gneiss and have garnet and staurolite developed in them.

The **Kaigas Series** lies conformably on the Stinkfontein beds and consists of shales, phyllites and limestones; the limestones are white, grey and dark blue, the latter giving off a foetid odour when broken up. The larger individual outcrops often exhibit isoclinal folding.

The **Numees Series** follows the Kaigas and is of special interest on account of the presence of a glacial tillite 800 feet (244 km) thick in it. Bands of small pebble conglomerate, grit and slaty rocks are also included in the series. The boulders and large pebbles are of gneiss, granite, quartz-porphyry, quartzite, quartzitic arkose, limestones, granulites and various schists and slates; no amygdaloidal or basic igneous rocks have been recorded in the tillite. Owing to the sheared condition of the rock the scratches believed to be due to glacial action have usually been obliterated, but characteristic striated boulders have been found in the series and the remains of the scratches are often preserved under the fine striae produced by shearing. The boulders, of which the largest recorded (of gneiss) projected eight feet from the surface, are scattered promiscuously in the grey-blue mudstone matrix, but often several boulders of one type of rock lie near each other.

The **Groot Derm Series** is the name given to a thick succession of green and purple slates, agglomerates, tuffs and andesitic or more basic amygdaloidal lavas; white or yellowish crystalline limestones also occur. Their position with regard to the Kaigas and Numees beds is uncertain. They may be older than the Numees tillite and may perhaps be part of the Kaigas series.

On the coast of Namaqualand between Port Nolloth and the mouth of the Orange River there are important outcrops of quartz-schists, quartzites and conglomerates (called Port Nolloth beds in Ann. Rep. Geol. Survey for 1912, p. 149); they contain boulders of gneiss and are often felspathic. Near Alexander Bay limestones, slates and sheared amygdaloidal lavas presumably belong to the same group. Their relation to the gneiss of Namaqualand is not known, nor is their relation to the Stinkfontein, Kaigas, Numees and Groot Derm Series (?Konkip formation) described under "Ventersdorp System", though it is quite possible that the Alexander Bay rocks belong to them. The red limestone boulders, found in the Numees Tillite, which in 1913 gave rise to the mistaken supposition that the tillite derived part of its material from the red Nama (Malmesbury) limestone seen in its true position in Neint Nababeep, could have come from beds exposed at Alexander Bay. It is therefore possible that the Port Nolloth-Alexander Bay beds are older than the Numees tillite. The quartzitic conglomerates of Cliff Point cannot be matched precisely in the Stinkfontein beds, but they contain many boulders of gneiss of which the source is not known. Possibly the Port Nolloth beds are of an age between those of the sedimentary and volcanic rocks enclosed by the gneiss of Namaqualand and the Numees beds.

Reference:

Rogers, A. W., Trans. Geol. Soc. S. Africa XVIII, 1915, pp. 84—94.

4. The Transvaal-Nama-System.

By

A. L. Hall.

With the exception of the Karroo System, the Transvaal-Nama-System is the most widely distributed group of sediments in the Union and shows the following three principal[1] developments:—

a) In the Transvaal Province it occupies large and continuous areas, the major portions of which encircle the great Bushveld Igneous Complex (see section No. 5) in the Central Transvaal, notably on the eastern, southern, and western margins of that intrusion; in the Eastern Transvaal, the system covers some 5200 square miles (13468 qkm) of country belonging to the Pietersburg, Lydenburg, Middelburg and Belfast Districts, while in the southern and western Transvaal it extends from the neighbourhood of Middelburg westwards through Pretoria and Zeerust to the Union-Bechuanaland Protectorate border (see Fig. 19). The latter distribution is also continued southward into the Potchefstroom and Vereeniging districts of the Southern Transvaal, where the system—along a portion of the Vredefort Mountain Land—passes across the Vaal River into the extreme northerly portion of the Orange Free State, but is soon covered by the overlying Karroo formation. In the southern and western Transvaal, the system thus occupies approximately 10000 square miles (25898 qkm), the whole distribution (including several minor areas of the Rooiberg Series) amounting therefore, to something like 17000 square miles (44027 qkm), equal to over 14 per cent. of the entire province (roughly 120000 square miles = 310182 qkm).

In the Central Transvaal occurs the Rooiberg Series, placed provisionally at the top of the System above the Pretoria Series and not found outside this province. The Rooiberg Series is closely connected with the Bushveld Igneous Complex, of which it forms the first or volcanic phase, composed almost wholly of acid lavas and some pyroclastic rocks with thin intercalations of quartzites and shales; these rocks form the roof of the great norite lopolith, and possibly a local unconformity separates then from the underlying Pretoria Series, now flooring the lopolith (see Section 5 below).

b) In the Northern portion of the Cape Province the Transvaal-Nama System occupies another large area, some 23000 square miles (59566 qkm) in extent, with an maximum width of over 95 miles (153 km), reaching from the neighbourhood of Prieska in a general northerly direction through the divisions of Prieska, Hay, Barkly West, Kuruman and Taungs across the Mashowing River into the division of Vryburg; the most northerly outcrop forms a detached inlier at the Morokwen Native Reserve (see Fig. 19). This devepolment includes the whole of the Asbestos Mountains (Kuruman Hills) as well as the extensive Kaap Plateau. But for the great distribution of surface deposits of the Kalahari type the system would probably stretch continuously from the Mashowing and Molopo Rivers north-eastwards to the Transvaal border.

c) In the Western region of the Cape Province this system is found in three separate areas (in addition to certain minor outcrops east of the Cape Peninsula, e. g. Oudtshoorn); the largest of these is in the south and is distributed round Malmesbury over the divisions of Piquetberg, Malmesbury, Paarl and Cape, including the so-called French Hoek Beds near Stellenbosch. Further to the north the second occurrence falls into the division of Van Rhyns Dorp in several irregularly distributed detached masses found between that village and Nieuwerust. The last

[1] The system is not found in the Natal Province.

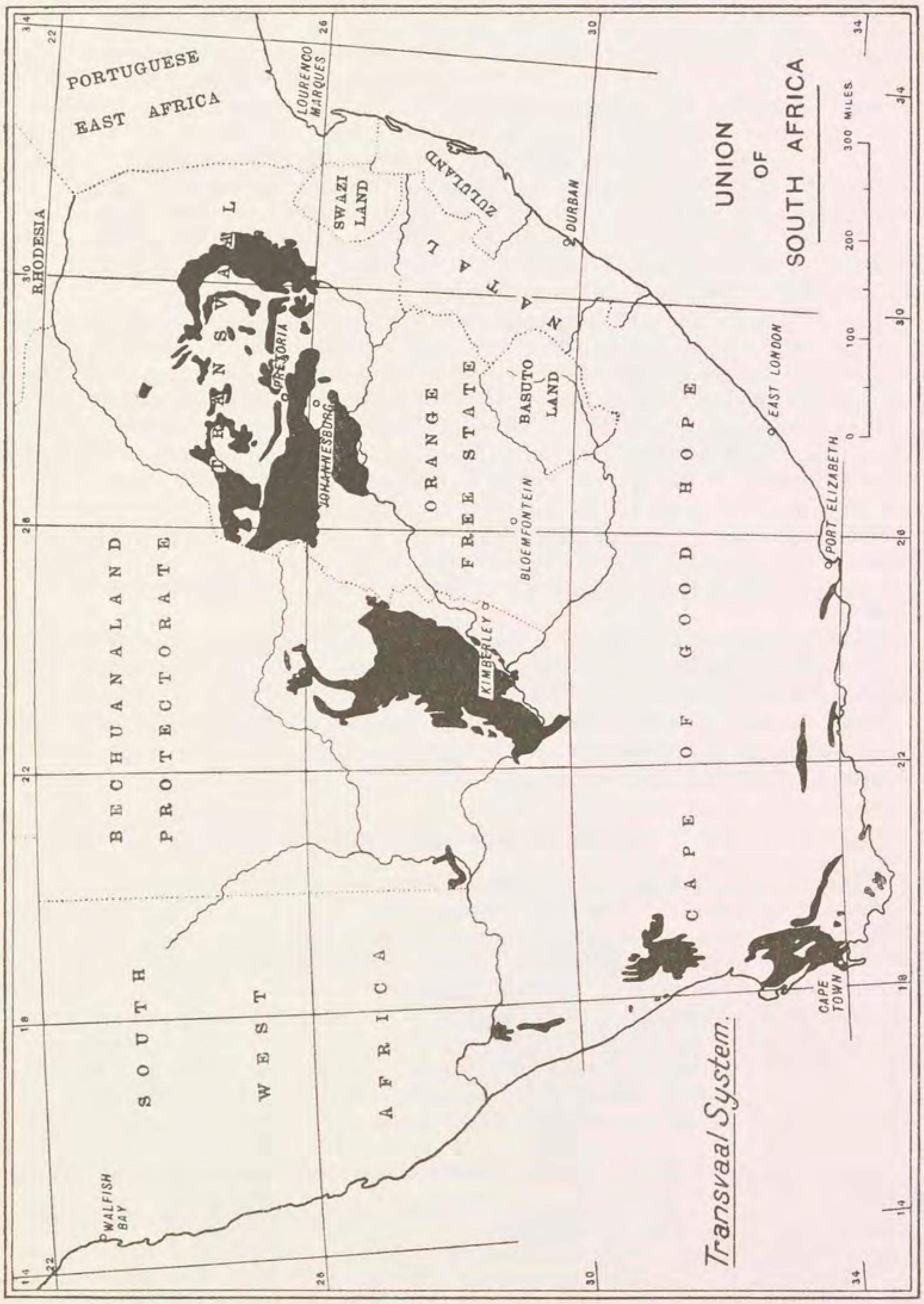

Fig. 19. Outline Map showing the distribution of the Transvaal System.

and most northerly outcrops belong to Namaqualand, where the system shows three or four minor areas generally trending from south to north; these reach from near Springbok past Steinkopf to Viols and Kwab's Drifts on the Orange River.

The system attains its most typical development in the Transvaal, where its leading sediments, i. e. quartzites, limestones and shales, show the maximum stratigraphical regularity; its designation is due to MOLENGRAAFF[1] and has been extended to the equivalent group as developed in the northern Cape Province. In the latter area the essentially argillaceous nature of the uppermost division of the System, characteristic of many outcrops in the Transvaal (Pretoria Series), gives place to a great development of siliceous banded ironstones (Griqua Town Series), while the middle or dolomitic division is also more varied here as compared with its Transvaal equivalent. It is convenient therefore to refer to a Transvaal Facies and a Northern Cape or Griqua Town Facies of the system.

In the western Cape Province the system shows the maximum variation in lithological characters, and is also much more irregular in its distribution; this has given rise to a considerable number of more or less local group names, the stratigraphical significance of which can only be defined approximately. The equivalents to some of the groups within the normal system have been recognised in South West Africa, e. g. the Schwarzkalk or Otavi limestone, corresponding to the Middle or Dolomite division of the system, and have been grouped under the name[2] Nama System; since the sequence of Pre-Cape rocks in the Van Rhyn's Dorp area is very similar to that in South West Africa, the term has been extended to cover the Transvaal System in the western Cape Province[3] as well. A third, i. e. a Western Cape Nama facies may therefore be recognised in addition to the two already referred to.

Fossiliferous remains have not[4] hitherto been discovered in this system.

The following table (page 75) shows the principal rock groups belonging to the Transvaal Nama System.

Basic intrusions, notably in the form of sheets, are strongly marked in the Pretoria Series of the Transvaal facies and represent the sill phase of the norite "lopolith" belonging to the Bushveld Igneous Complex. (See section 5).

a) The Transvaal Facies.

In the northern most province the system forms a more or less well marked girdle of sediments encircling the Bushveld Complex, over a belt of country up to 60 miles (97 km) wide. The depression of the floor due to this enormous intrusion has determined a structure of regional simplicity, since the strata all along the girdle dip into the central magmatic basin, i. e. in the Eastern Transvaal to the west, along the southern margin to the north, in the western Transvaal to the east, and along the northern margin of the Complex to the south; the much greater areal distribution of the system in the western Transvaal is largely due to the low inclination. Locally, e. g. in the Haenertsburg Goldfields on the north-east round Pretoria and along the intrusive transgression round Potgietersrust in the north the structure is complex,

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[1] MOLENGRAAFF, G. A. F. "Géologie de la République Sud-Africaine du Transvaal." Paris, Bull. Soc. Géol. 1, 1901, pp. 13—92.

Other names are "Potchefstroom System" (HATCH and CORSTORPHINE) 1905; and "Lydenburg Beds" (HATCH and DUNN and PASSARGE).

[2] SCHENK, A. Zeitschr. Dtsch. Geol. Ges. 1885, p. 534.

[3] ROGERS, A. W. "The Nama System in the Cape Province", Trans. Geol. Soc. S. Africa, 1912, Vol. XV, p. 35.

[4] With the exception of a probable Brachiopod shell in the Campbell Rand near Schmidt's Drift, west of Kimberley.

Succession of Transvaal-Nama System.

Transvaal Facies	Griqua Town or Northern Cape Facies	Western (and Southern) Cape or Nama Facies
Rooiberg Series, Felsites, Quartzites, Shales	— — — —	— — — —
Pretoria Series, Shales, Quartzites, Lavas	Upper Griqua Town Series, Ferruginous Slates, Jaspers, Quartzites Middle Griqua Town Series = Ongeluk Series Lavas, Jaspers, etc. Lower Griqua Town Series, Ferruginous Slates, Jaspers, Tillite	Ibiquas, French Hoek Series N.B. In Van Rhyn's Dorp an unconformity lies between the Ibiquas and Malmesbury groups
Dolomite Series, Dolomite, Slates, Chert	Campbell Rand Series, Dolomites, Chert, Slates	Malmesbury Beds (including the Aties group), Cango Series, Nieuwerust Beds
Black Reef Series, Quartzites, Slates, Conglomerates	Black Reef Series, Quartzites, Grits, Conglomerates	

since the intense pressure depending on the mechanics of intrusion found relief in much faulting and folding. This is scenically reflected most strikingly in the mountains along the Strydpoort Range in the north-east, where both the Dolomite and the lower portion of the Pretoria Series are sharply folded.

West of Johannesburg the system develops an anticlinal structure through which the former is continued southward into the well defined Potchefstroom syncline, where the Black Reef Series and the Dolomite group share in the overtilting of the succession that appears to be genetically associated with the updoming of the Vredefort Granite[1]. Still further west between Lichtenburg and Klerksdorp the underlying formations, e. g. the Ventersdorp System, are exposed between the two anticlinal branches of the Black Reef Series.

North of Potgietersrust, where the Bushveld Complex has broken in a northerly direction across its girdle of the sediments, each horizon of the system is in turn transgressed by the basic margin of the complex, a phenomenon accompanied by the disappearance—probably through assimilation combined with uplift and subsequent denudation—of substantial thicknesses of the succession e. g. in case of the Black Reef Series near Uitloop (compare Section No 5 below).

Extensive blocks of strata—notably of the Dolomite and the Pretoria Series—are sometimes found well inside the Complex itself, surrounded by Bushveld Granite, and may represent upstoped portions of the floor or gigantic xenolithic fragments, e. g. round Marble Hall in the Elands River Valley north-east of Pretoria or round the junction of the Aapies and Crocodile Rivers north of Brits, where the "inclusion" occupies over 200 square miles (512 qkm) of country.

[1] A. L. Hall and G. A. F. Molengraaff: "The Vredefort Mountain Land in the Southern Transvaal and the Northern Orange Free State", Verh. Kon. Akad. Wet. 1925, Amsterdam, ch. II and V.

1. The Black Reef Series.

This name is derived from the occasional presence of black carbonaceous matte- in some of the gold bearing conglomerates; though locally well marked, e. g. southr west of Pretoria, this is by no means a constant feature. The Black Reef Series rests very often with a purely sedimentary junction upon the Older Granite, from the disintegration of which an arkose band, often with much pink felspathic matrix, is frequently developed; this varies from a few inches to a few feet. Elsewhere the series rests upon the Ventersdorp System, and (quite exceptionally owing to the local inversion of the succession) in the Vredefort Mountain Land it rests on the base of the Dolomite Series.

The formation is essentially arenaceous, and quartzites or quartzitic sandstones, predominate markedly over slates and conglomerates, but the latter, though always thin, are a persistent feature and locally auriferous (See Economic Geology p. 170).

With reference to the Bushveld Complex the Black Reef Series determines the extreme outer margin of the sedimentary girdle built up of the Transvaal System and thus extends without interruption from Potgietersrust eastwards along the Strydpoort and then southwards along the Transvaal Drakensberg to Carolina, where it passes under the Karroo System, to reappear south of Pretoria and encircle the northern margin of the Half Way House granite, whence it continues westwards to beyond Zeerust. Through folding, the series also branches southwards towards Klerksdorp and is likewise an element in the curvilinear disposition of the Vredefort Mountain Land. In the north-eastern and eastern Transvaal, where it attains its maximum thickness, the series determines the powerful escarpment of the Drakensberg and gives rise to some of the most striking scenery in the northern parts of the Union, culminating in peaks nearly 7000 feet (2134 m) above sea level.

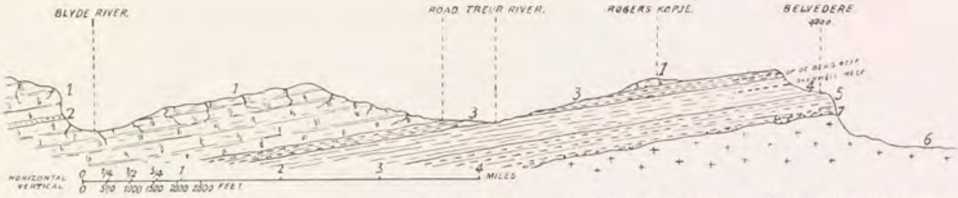
The top of the series is often not sharply defined, and in the Sabie-Pilgrims Rest portion of the Eastern Transvaal specially, a transition zone, some 30 feet (9.1 m) thick and built up of an alternating series of dolomite and dark coloured quartzite, with occasional partings of shale and coarse sandstone, intervenes between the Black Reef and the overlying Dolomite Series.

North of Pilgrims Rest, where the sequence is very regular and well exposed, the detailed succession is as follows:—

Dolomite Series		Dolomite, Chert, etc. At the base lies Dolomite alternating with sandy quartzites.
Black Reef Series	Passage beds.	Shaly Sandstones.
	Upper Quartzite Group.	Quartzites—200 feet (61 m)
	Middle Shale Group.	Shales, Shaly Sandstones—500 feet (152 m)
	Lower Quartzite Group.	Quartzites—500 feet (152 m) conglomerates at base.

The threefold division of the series in the north-eastern Transvaal is very clearly marked north of Pilgrims Rest (See Fig. 20), the Lower Quartzite group determining the escarpment, while the Upper Quartzite group builds the dip slopes.

The fresh normal quartzites are evenly medium-grained, very pale bluish rocks, becoming pale creamy white in outcrops long exposed to weathering, or they may show delicate yellow strands following lines of bedding and due to decomposed ferruginous matter (Devils Kantoor). Current bedding and smooth well rounded scattered pebbles are common. The shaly sandstones and arenaceous shales of the Middle Group are soft thinly bedded rocks with a constant admixture of sandy matter; a strikingly variegated appearance due to many thin layers of different colours is common. At the bottom of the Lower Quartzite group lies a persistent



1. Dolomite. 2. Blyde River Quartzite. 3. Upper Quartzite Group. 4. Middle Shale Group. 5. Lower Quartzite Group. 6. Granite. 7. Conglomerate.

Fig. 20. Section across the Black Reef Series at Belvedere, Pilgrims Rest District, Transvaal Province.

horizon of conglomerate, which has been traced along the entire length of the Strydpoort Range and the Drakensberg as far south as Carolina, as well as south of Pretoria and elsewhere in the western Transvaal. At the Pennyfather Mine near the northernmost point of the Drakensberg the main conglomerate band is 4 to 5 feet (1.5 m) thick and underlain by a similar thickness of hard bluish pebbly quartzite, which is succeeded by a second conglomerate, 2 to 3 feet (1 m) thick. The latter rests on several hundred feet of finely bedded greyish shaly sandstone, not developed further south; these are separated by 6 feet (2 m) of pebbly arkose from the underlying Older Granite. The detailed succession is as follows:—

	feet	m
Upper Quartzite Group	250	76.2
Middle Shale or Flagstone Group	1500	457
Lower Quartzite Group with Conglomerates . .	150	46
Lower Flagstones	400	122
Pebbly Arkose	6	1.8
	2306	703

The conglomerates are coarse, and show a hard bluish quartzitic matrix sometimes carrying auriferous pyrites and crowded with smooth well-rounded pebbles ranging in diameter from 2 or 3 inches (5 or 7.6 cm) up to half a foot and over. They consist of white coarse glassy quartz, fine grained opaque white sugary quartzite and occasionally of striped or banded material; some of these pebbles were probably derived from the resistant elements of Moodies Series, including the calico rocks, banded ironstones and jaspery rocks of that formation.

The Black Reef Series varies in thickness between wide limits and reaches its maximum development in the northern sector of the Drakensberg between Belvedere and the Wolkberg; included in this is the stupendous pile of Marieps Mountain which overtowers the precipitous cañon of the Blyde River. The series is very thin south-west of Pretoria, where the dark almost black shaly passage beds at the top are well marked. On Rhenosterspruit along the Broederstroom-Johannesburg main road, the following section occurs:—

		feet	m
Dolomite Series	Massive dolomite, chert etc.		
	Dark coloured finely-laminated shales	5	1.52
	Massive dolomite	10	3.05
Black Reef Series	Dark coloured, finely laminated shales	30	9.14
	Hard thickly bedded quartzite	3	0.91
	Dark coloured finely laminated shales	29	8.84
	Hard quartzite, floored by granite	6	1.83

Igneous intrusions are very rare and represented in the Eastern Transvaal by a well defined basic dyke cutting across Marieps Mountain.

The following table shows the variation in approximate thickness:—

	feet	m		feet	m
Chunies Poort	1600	488	Sabie	200	61
Wolkberg	2300	701	Sibthorpe's Store	60	15
Marieps Mountain	2500	762	Devils Kantoor	80	21
Belvedere	1260	384	Komati River Valley	20—30	6.1—9.1
Lisbon-Berlyn	1200	366	Near Carolina	20	6.1
Mac Mac	700	213	South west of Pretoria	30	9.1
Klip Kraal	420	128			

2. The Dolomite Series.

The middle division of the system forms a great succession of thickly bedded dolomite, with a thin development of slates, two or three horizons of banded ironstones, and one minor band of quartzite. Its distribution is similar to that of the Black Reef Series, the dolomite occupying a somewhat narrow strip of country falling into the sedimentary girdle of the Bushveld Complex, but lying nearer the margin of that intrusion. Excepting in the eastern and north-eastern Transvaal, where the formation (in places strongly folded) forms part of mountainous country between Potgietersrust and Haenertsburg (Makapan's Mountains and the Strydepoort Range) or from Sabie to the Olifants River, the dolomite series forms a gently rolling elevated country, specially where it becomes thicker and lies inclined at low angles, e. g. south of Pretoria. In the Western Transvaal it covers some 2000 square miles (5180 qkm) of tableland reaching from Krugersdorp past Lichtenburg to Ottos Hoop.

The base of the system is rarely definite and often shades into the underlying Black Reef Series through a zone due to an alternating series of calcareous and quartzitic rocks (see above). At the top there is sometimes a similar uncertainty, but commonly a thick band of hard chert, known as the "Giant" Chert marks the upper limit; possibly a slight local unconformity occurs along this horizon; in places a narrow zone of passage beds is found, showing an alternation of shale and dolomite (Fountains Valley south of Pretoria); elsewhere the top of the series is marked by Bevets Conglomerate or by the Rooihoogte quartzite.

The bulk of the dolomite Series is built up of very thickly bedded almost massive light to dark grey dolomitic limestone or dolomite, usually finely crystalline, and very fresh. Surfaces long exposed to weathering have a highly characteristic dark gray to black furrowed appearance, resembling elephants skin, from which the description "Olifantsklip" is derived. This rock has a most important influence, in this as well as in the Griqua Town facies of the system, on the water supply, owing to its taking up large volumes in fissures and cavities, and returning this water from powerful springs, so that it is the only formation in the Union which can be said to be water bearing on a large scale, though the supply is not held by the rock itself but is in the widened joints and other spaces. The ease with which percolating waters carrying carbon dioxide act as solvents of carbonate rocks leads to many caves and similar solution spaces; some of these are very extensive and may deposit a pure form of lime of economic importance (Godwan River, Makapan's Caves, etc.). Sink holes, into which streams disappear, and the so-called "Wondergaten"—representing caves with fallen roofs—are also characteristic, while in regions of greater relief the succession of thick dolomite strata gives the slopes a well marked terraced appearance (Godwan River valley, Haenertsburg Goldfields etc.). Chert is widespread in many thin often very regularly interbedded layers ("Sandwich" Structure) of compact silica, rarely more than a few feet thick, but becoming very prominent at the top of series in the Central Transvaal—"Giant" Chert. The intimate association between resistant silica and the more soluble carbonate material leads to many fantastic forms of weathering, some of which have a strong superficial resemblance to organic remains (e. g. in the Western Transvaal).

Interbedded hard compact highly siliceous and thinly bedded ferruginous layers —known as *banded ironstones*—are also found, and become marked in the sector extending from Potgietersrust southwards and eastwards at least as far as the Steelpoort-Olifants River junction. These bands vary from 80 (24.4 m) to about 150 feet (45.7 m) in thickness and are very hard dark brownish slaty rocks sometimes slightly jaspery and now and then carrying delicate cross-fibre seams of asbestos (amosite). Commonly the banding is due to alternating layers (often strongly contorted) of impure yellowish to pinkish jaspery quartz and black or deep brownish hematite. Such rocks show a very close resemblance to the banded ironstones building the Griqua Town Series in the northern Cape Province.

From Sabie in the Eastern Transvaal northwards at least as far as Belvedere extends a thin but very regularly persistent band of *quartzite*; this is known as the Blyde River quartzite[1], situated in the lower portion of the Dolomite from 200 (61 m) to 500 feet (152 m) above the Black Reef Series between Sabie and Frankfort, and from 2 to 15 feet (0.61 to 4.57 m) thick. It is a greyish to bluish rock, somewhat variable in texture and locally coarse and conglomeratic; this quartzite is almost invariably overlain by the "Lower Shale Band".

Argillaceous rocks in the Dolomite are found along three horizons—notably in the Pilgrims Rest area, and are known as the Upper, Middle, and Lower Shale Bands; here the Upper band lies 600 feet (183 m) below the base of the Pretoria Series and consists of four to six feet of dark greyish white to faintly bluish somewhat thickly bedded indurated shaly mudstones. The Middle band is the most persistent and from 10 to 30 feet (3.04 to 9.14 m) thick, situated approximately 250 feet (76 m) below the top band; it consists of hard compact dark bluish grey mudstones. At a horizon of from 200 to 300 feet (61 to 91.4 m) below the Middle band lies the Lower Shale group resting directly on the Blyde River quartzite and forming either a single band a few feet thick, or several, separated by dolomite.

Thin admixtures of *manganese earth* (wad) are widely distributed at various horizons specially a little below the base of the Pretoria Series, but are economically negligible.

The detailed succession in the Pilgrims Rest area is therefore as follows:—

		feet	m
Pretoria Series	Shales		
Dolomite Series (approx. 1300-1700 feet [400—520 m])	Giant Chert; Dolomitic Limestone and Chert	600	183
	Upper Shales	4—6	1.2—1.8
	Dolomitic Limestone and Chert	250	76
	Middle Shales	10—30	3.0 — 9.1
	Dolomitic Limestone and Chert	200-300	61—91.4
	Lower Shales	2—5	0.61— 1.52
	Blyde River Quartzite	2—15	0.61— 4.5
	Dolomitic Limestone and Chert	200-500	61—152
	Dolomite interbedded with Quartzite		
Black Reef Series	Shaly Sandstone Passage beds.		
	Quartzite, etc.		

Igneous rocks are rare and found as a few intrusive sills and dykes. In the Godwan River valley on the Kaapsche Hoop (Devils Kantoor) Plateau lies a persistent sheet a few yards above the Black Reef quartzites and about 4 feet (1.22 m) thick, composed of pale dirty greenish diorite, built up mainly of plagioclase and

[1] Locally referred to as the "Middle Sandstone".

hornblende, together with ilmenite and augite. A few yards below the top of the Series is another persistent sheet found both on the south (Carolina) and on the north (Chuniespoort); it is in contact with serpentinised dolomite carrying cross fibre seams of high grade chrysotile asbestos. Other sills occur in the dolomite area south of Pretoria. Here is also found a powerful south and north dyke of greenish gabbro somewhat mottled with pink felspar and extending for at least 20 miles 32 km) from south of Irene northwards across the Pretoria valley into the basic margin of the Bushveld Complex. Cutting roughly from north-north-east to south-south-west across both Black Reef Series and Dolomite is a prominent dyke on Coetzestroom in the Godwan River basin; it is also a basic type and intimately associated with the auriferous deposits in the Barretts Berlyn area. Sills are also well marked in the Pilgrims Rest goldfields, notably in association with the gold bearing quartz reefs a little below the base of the Pretoria Series; here other dykes also occur and may assume economic importance[1] (Vaalhoek Dyke, Mali Dyke, etc.).

The great majority of these intrusions are almost certainly of pre-Karroo age and closely resemble the sill phases of the norite belonging to the Bushveld Igneous Complex, but at least one dyke north of Pilgrims Rest is an olivine-bearing dolerite most likely of post-Karroo age.

Where the dolomite falls within the contact belt of the Bushveld Complex it leads to black or dark bluish rocks, which retain their bedded structure but show conspicuous contact minerals, i. e. actinolite, scapolite, and tremolite in scattered needles and rosettes (Chuniespoort, South of Zeerust, etc.). Where portions of the Dolomite have been caught up as fragments in the Bushveld Granite, or where the Complex north of Potgietersrust transgresses the Series, intense metamorphism produces crystalline marble (Marble Hall north-east of Pretoria), or lime-silicate hornfelses with malacolite, garnet, wollastonite, zoisite, etc.

The variation in thickness is considerable, as shown in the following list:—

	Approximate Thickness feet	m
Haenertsburg Goldfields	3500	1067
Elandsfontein, N. of Pilgrims Rest	3000	914
Pilgrims Rest	1700	518
Sabie	1000	305
Godwan River	970	295
East of Carolina	120	37
South of Pretoria	3000	914

3. The Pretoria Series[2].

This is the most widely distributed formation of the Transvaal System, and, excepting over the great Potchefstroom syncline southwest of Johannesburg, occupies the innermost belt of the sedimentary girdle surrounding the Bushveld Complex, with the basic margin of which the series is for many miles—almost all round the intrusion—in direct contact, and hence intensely metamorphised through thousands of feet of its succession.

The Pretoria Series is built up almost wholly of quartzites and shales, with subordinate calcareous bands and conglomerates, but includes several horizons of volcanic rocks, together with a glacial deposit, but the latter has not so far been definitely recognised in the Transvaal Province. Within the latter there is much lateral variation in facies, due to changes in the number and thickness of the quarzites

[1] Wybergh, W. "The Economic Geology of Sabie and Pilgrims Rest", Memoir No. 23, Geol. Surv. Union of S. Africa, Pretoria, 1926.

[2] Sometimes also referred to as the Gatsrand Series after a prominent feature south-west of Johannesburg.

occupying the leading arenaceous horizons, to the extreme variation in iron content in certain quartzites, to the gradual establishment of new horizons of conglomerates or quartzites, to the gradual transition of shales into banded ironstones, to the progressive intensity of metamorphism resulting in the passage of soft shales into holocrystalline cordierite-gneisses (M'Phatlele's Location; see section No. 5), and to the establishment of additional horizons of lavas. Hence sections of the Series from different parts of the province differ considerably in detail.

Notwithstanding this variation, the succession maintains a similar general framework throughout the province, due to three persistent horizons of quartzites:— The Magaliesberg Quartzite, the Daspoort Quartzite, and the Timeball Hill Quartzite, each of which may consist of one or several bands. Their highly resistant nature, compared with the intervening soft shales—or even with their indurated metamorphic equivalents— and the prevailing somewhat higher inclination, lead to prominent features continued for many miles—the so-called "Banken Scenery". The Pretoria Series is subdivided as follows, in descending order:—

1. The Magaliesberg Beds, reaching from the top of the Magaliesberg Quartzite (generally the extreme margin of the norite "lopolith" of the Bushveld Complex) to the top of the highest Daspoort Quartzite; shales and intrusive sills intervene between these limits; locally also lavas.
2. The Daspoort Beds, extending from the top of the highest Daspoort quartzite down to the top of the uppermost Timeball Hill quartzite; shales and intrusive sills intervene, with subordinate ironstones, and a persistent thick belt of amygdaloidal lavas, resting on the thin subsidiary Ongeluk quartzite.
3. The Timeball Hill Beds, reaching from the top of the uppermost Timeball Hill quartzite to the base of the Series, i. e. to the top of the Giant Chert of the underlying Dolomite Series, or to the base of the Rooihoogte Quartzite elsewhere; a great thickness of slates with very rare basic sills lies below the Timeball Hill quartzite horizon.

The lateral variation of the series is best followed by comparing the dominant horizons in the type sections directly west of Pretoria for the central, south of Lydenburg for the eastern, and at Malips Drift for the north-eastern and northern Transvaal; the generalised classification given above is approached closest by the Pretoria type section. The following table brings out the major differences (p. 82).

The uncertain position of the base of the series has been referred to above, and is due to the presence of passage beds showing an intermingling of dolomite with shale or banded ironstones, or it is obscured by basic sills (Pilgrims Rest), but elsewhere the base is more clearly defined by the Bevets Conglomerate or by the bottom or the Rooihoogte quartzite (east of Carolina).

The Magaliesberg, Daspoort and the non-ferruginous facies of the Timeball Hill quartzites are thickly bedded, hard, light-coloured, medium-grained rocks, often indistinguishable from one another. At Pretoria and westwards the Magaliesberg band stands out as a bold and persistent linear feature and consists of a single quartzite some 1000 feet (305 m) thick, but locally there are several bands separated by basic sill phases of the Bushveld Complex; thus, at the Hartebeestpoort dam, 25 miles (40 km) west od Pretoria, the following section occurs:—

Main Bushveld Complex		
Upper Quartzite	420—460 feet	(128—140 m)
Upper basic Sill	90—125 feet	(27—38 m)
Middle Quartzite	65—160 feet	(20—49 m)
Lower Basic Sill	450 feet	(137 m)
Lower or Main Quartzite	1000 feet	(305 m)

Comparison of the three Type Sections of the Pretoria Series (Transvaal Facies).

Central Transvaal (West of Pretoria)	feet approx.	m approx.	Eastern Transvaal (South of Lydenburg or east of Belfast-Dullstroom)	feet approx.	m approx.	North-Eastern and Northern Transvaa (Malips Drift).	feet approx.	m approx.
[Absent]			Dullstroom Volcanic Series	1200	370	[Absent]		
Magaliesberg Quartzite (normally one band)	1000	300	Witrand or Steenkampsbergen (several bands)...	3000	900	Tokane Mountains of Sekukuniland (one band)	100	30
Slates with thick dolerite sills [Absent] Slates with thin sills	5200	1585	Slates (altered) with thick sills. .... Machadodorp Volcanic Series (600—1000 feet). Slates with thin sills.	3000	900	Highly altered slates. Sills few. Thin or absent. Highly altered slates. Sills rare.	2200	670
Daspoort Quartzite (one band)	120-200	35-60	Upper Quartzite (10-20 feet) Slates and sills. .... Middle or Tunnel Quartzite (80—100 feet) Slates. Lower or Dwaal Heuvel Quartzite (100 feet).	700	210	Sakune Mountains (one band only)	80	24
Slates with basic sills. Ironstone Band. Slates. Amygdaloidal Andesite. (=Ongeluk Series of Cape). Ongeluk Quartzite. Slates with basic sills.	5600	1700	Slates with basic sills. [Absent]. Slates with basic sills. Amygdaloidal Andesite. Ongeluk Quartzite. (15 feet) Slates with basic sills.	1800	550	Altered slates with basic sills. [Absent.] Altered slates with basic sills. [Absent]. [Absent]. Altered Slates. Sills rare.	1800	550
Timeball Hill Quartzite (several and in part ferruginous, and 8—10 feet thick) Slates with rare or no sills	1250	380	Upper Nooitgedacht Quartzite (magnetic); 2—5 feet. Slates or sills. Lower Nooitgedacht Quartzite (sometimes magnetic); 20 feet.	350	107	Timeball Hill Quartzite (single non-ferruginous band)	120	35
[Both Absent]			Slates with very thin quartzites Bevets Conglomerate or Rooihoogte Quartzite	2550	777	Altered Banded Ironstones. Bevets Conglomerate. [Absent]	4000	1220
Chert and Dolomite.			Chert and Dolomite			Chert and Dolomite		
Approx. Total Thickness	13100	4000		12400	3800		8300	2530

The intense metamorphism by the Bushveld Complex has produced extremely coarse glassy phases extending some distance into the main band (Doornpoort type). In the Eastern Transvaal the Magaliesberg quartzite is represented by at least four separate bands, ranging from 200 (61 m) to nearly 1000 feet (305 m) in thickness and playing a prominent part in the complex mountainous country of the Witrand and Steenkampsbergen from near Belfast northwards to the Steelpoort River, where they collectively occupy a strip of country some 10 miles (16 km) wide, and are associated with basic sills of great thickness, and with crystalline cordierite hornfels; they are accompanied by several thin additional quartzites (Fig. 21).

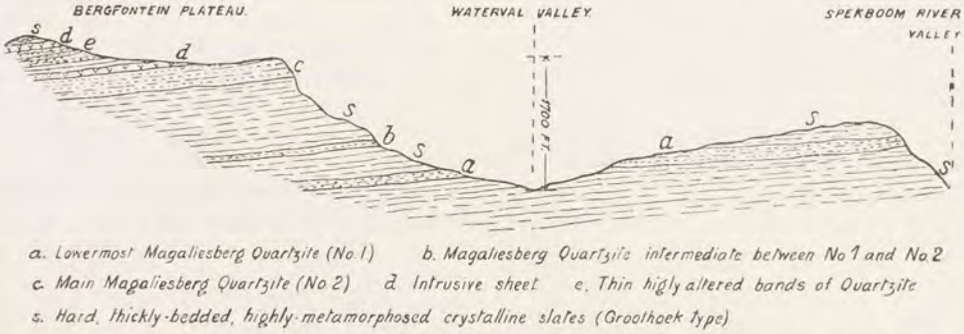


Fig. 21. Section across the valley of the Waterval River on Buffelsvlei, north-west of Lydenburg. Transvaal Province. (Magaliesberg Quartzite Horizon).

a. Amygdaloidal andesite. d. Dolomite. db. Intrusive sheet. s. Shales. T. Tunnel Quartzite. H. Dwaal Heuvel Quartzite. N. Nooitgedacht Quartzite.

Fig. 22. Section across Kranskloof, near Kruger's Post, north of Lydenburg, Transvaal Province. (Daspoort Quartzite Horizon).

Still further north the quartzites die out, only a single band continuing as the Tokane mountains beyond the Steelpoort River through Sekukuniland, only about 100 feet (30 m) thick.

The Daspoort Quartzite is a single band in the Pretoria section, but forms three separate quartzites in the Eastern type section; these continue northwards to a few miles north of Ohrigstad (beyond Lydenburg) and are known as the Upper (not always found), the Middle or Tunnel, and the Lower or Dwaal Heuvel quartzites. Their low dip and resistant characters determine much of the highly sculptured surface in the country round Waterval Boven and Lydenburg (Fig. 22).

North of the Steelpoort River only a single band remains and persists across Sekukuniland, where it is 80 feet (24.4 m) thick and builds the Sakune Mountains, through Malips Drift to Potgietersrust, being finally cut off (like the rest of the Series) by the intrusive transgression of the Bushveld Complex.

Fig. 23. Section across Sham Sham, south of Mount Anderson, Lydenburg District, Transvaal Province. (Timeball Hill Horizon).

1. Dolomite. 2. Shales and Slates (Pretoria Series). 3. Lower Nooitgedacht Quartzite (Timeball Hill Series). 4. Diabase. 5. Upper Nooitgedacht Quartzite (Timeball Hill Series).

At Pretoria the Timeball Hill quartzites consist of at least ten separate bands, ranging from 1 to about 20 feet (0.30 to about 6.1 m) in thickness and separated by shales; some of these bands are light-coloured to almost white rocks, free from iron, while others are heavy black magnetite-quartzites; similar relationships hold good for many miles west of the Capital. The presence of much dark ferruginous matter is a strong characteristic which distinguishes them from the two higher main horizons. The same holds good for the Eastern Transvaal where these rocks are known as the Nooitgedacht[1] quartzites, and often stand out in the scenery (Fig. 23).

[1] Named after their prominent outcrops at Airlie Station (formerly called Nooitgedacht) on the Delagoa Bay railway.

On the north bank of the Komati River Valley occurs the following section— typical of the fullest development of this horizon in the Eastern Transvaal: —

	feet	m
Shales and Slates with thin dolerite sills.		
Upper Nooitgedacht Quartzite (top band), hard black highly ferruginous layer.	1	0.30
Thinly bedded Flagstones		
Upper Nooitgedacht Quartzite (middle band) like the topmost band	1	0.30
Thinly bedded Flagstones.		
Middle Nooitgedacht Quartzite, less ferruginous	3—4	0.91-1.2
Flagstones.		
Lower Nooitgedacht Quartzite. Thickly bedded hard deep black and highly ferruginous band	20—25	6.1-7.6
Flagstones.		

The above succession represents altogether some 200 feet (61 m), in which the quartzites are usually strongly magnetic and have a high specific gravity. Similar associations are maintained northwards to the Steelpoort River valley, where facies changes due to variable conditions of sedimentation seem to have caused the iron admixtures to cease and to develop with rapidly increasing intensity in the underlying shales (see below), so that the Timeball Hill horizon passes through Sekukuniland to Potgietersrust as a single band of thickly bedded quartzite free from ferruginous matter and 120 feet (36.5 m) thick.

Among less persistent arenaceous horizons, the Ongeluk and Rooihoogte quartzites are of special interest. The Ongeluk quartzite is well seen e. g. in the Tolani River valley north of Rondavel Siding in the Western Transvaal and in the Elands and Komati River basins south of Airlie Station on the Eastern Line, where it is some 15 feet (4.57 m) thick, but it reaches its greatest development at Ohrigstad north of Lydenburg. Its main interest lies in its close similarity in stratigraphical position to the glacial conglomerate found in the Lower Griqua Town Series of the Cape Facies (see below).

At Ohrigstad (see Fig. 24) the quartzite lies in the following succession:—

Daspoort Quartzite
Amygdaloidal Andesite = Ongeluk Series
Thinly bedded shales
Quartzite (= Ongeluk Quartzite)
Conglomerate, 12 to 18 feet (3.66—5.49 m)
Micaceous sandstone
Shales

(Quartzite, conglomerate, micaceous sandstone and shales together: 25 to 30 feet (7.62 to 9.14 m))

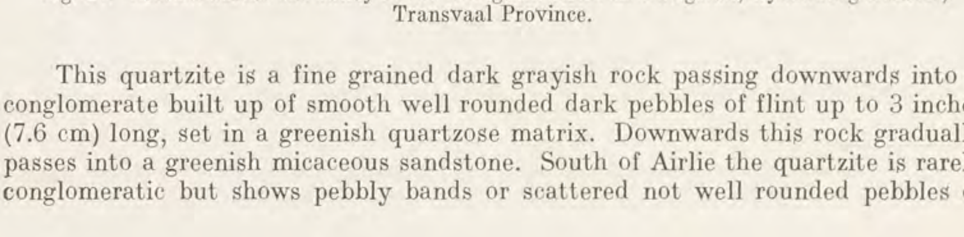


Fig. 24. Section across the valley of the Ohrigstad River at Ohrigstad, Lydenburg District, Transvaal Province.

This quartzite is a fine grained dark grayish rock passing downwards into a conglomerate built up of smooth well rounded dark pebbles of flint up to 3 inches (7.6 cm) long, set in a greenish quartzose matrix. Downwards this rock gradually passes into a greenish micaceous sandstone. South of Airlie the quartzite is rarely conglomeratic but shows pebbly bands or scattered not well rounded pebbles of compact cherty quartz. Definite evidence of glacial action has not hitherto been found at this horizon.

The Rooihoogte quartzite lies right at the base of the series and is up to 20 feet (6.1 m) thick, but apparently restricted to the Elands River and Komati River valleys in the Eastern Transvaal; its upper 2 or 3 feet (0.6 or 0.9 m) become locally conglomeratic; the reddish quartzitic matrix may diminish lower down, when the pebbles increase in size and number, until the bulk of the band becomes cherty and closely resembles the chert characteristic of the extreme top of the underlying Dolomite Series.

Argillaceous rocks are represented by various shales, slates, and flagstones which form the bulk of the Pretoria Series; they include a clay-band ore, situated a little above the Timeball Hill quartzites at Pretoria, which is of great economic importance as a domestic iron ore, in conjunction with associated magnetite-quartzites. The shales are soft, reddish, grayish or pale bluish rocks, usually forming the valleys separating the quartzite ridges, unless indurated by the intense metamorphism and complete recrystallisation into hard black hornfelses of many kinds. This effect is due to the intrusion of the Bushveld Complex and is progressive, so as finally to embrace the entire Pretoria Series in the north-eastern (Malips Drift) and western (Zeerust) region (see below under Section 5, p. 106).

A well defined ironstone band lies between the Daspoort quartzite and the top of the underlying lavas; though only a few feet thick at Pretoria, it increases enormously westwards, until it becomes several hundred feet thick round Rustenburg and Zeerust and gives rise to a group of prominent hills. Its main interest lies in the fact that it forms one of the connecting links between the Transvaal and Cape Facies of the Transvaal System.

The thinly bedded hard siliceous ferruginous slates or quartzitic slates known as banded ironstones are not found in the Pretoria Section, nor in the Eastern Transvaal, but only begin to appear along the Steelpoort River section north of Lydenburg, where they are restricted to the lower portion of the series from the Timeball Hill quartzite down to the base; from here they form almost the sole type of rock within that portion and continue right along to Potgietersrust, reappearing westwards, in the Crocodile River valley (where they form an important source of iron ore on Buffelshoek) and maintained thence to the Transvaal border. In the Steelpoort River valley this change is effected rapidly through the introduction of arenaceous and ferruginous material, until the true banded ironstones, with their layers of hematite and pinkish and jaspery bands and with their complex minor contortions, become practically indistinguishable from the typical beds of the Griqua Town Series in the northern Cape Province; like these, they have acquired economic importance owing to their asbestos content. (See Economic Geology, p. 201).

Conglomerates are rare. Most quartzites of this series show scattered pebbles and pebbly wastes, but only the Daspoort quartzite shows this as a more persistent feature. Bevets Conglomerate runs for many miles in the Eastern Transvaal from Sabie to Chuniespoort and acquires a special habit through its abundant roughly rectangular pebbles of striped and banded rocks. In the Chunies River valley near Naauwpoort the intense pressure to which the succession was subjected by the emplacement of the Bushveld Complex has cut up the rock by smooth joint-planes in several directions and resulted in the pebbles becoming facetted in a remarkably regular manner.

Calcareous bands are exceptional; the most persistent horizon lies at the top of the Magaliesberg quartzite (Central and Northern Transvaal) or within its several bands (Eastern Transvaal), traceable more or less all round the Bushveld Complex margin and is a pale greenish compact serpentinised dolomite several yards thick; at Potgietersrust the intense metamorphism due to this Complex has converted the rock into medium to coarse grained crystalline lime-silicate hornfels, carrying abundant garnet and wollastonite; this phase forms a local building stone. The same band occurs in the Wemmershoek valley north of Dullstroom, also east of Belfast, and at Edendale east of Pretoria, occasionally showing cross fibre seams of chrysotile asbestos. Xenoliths of intensely altered sediments carrying green massive grossularite garnet (so-called "South African Jade") and zoisite are met with surrounded by the Bushveld norite near Rustenburg and in Sekukuniland, and probably represent contact-metasomatically altered upstoped fragments of the same band. Also high up in the series several thin bands are found in the area north-west of Belfast and on the Bergfontein plateau within the Waterval River valley west of Lydenburg. Lower horizons occur near Ohrigstad (with large septarian nodules) and on the higher slopes of Van Lennep's Kopje at Machadodorp; here is a band of finely crystalline greyish limestone between 2 and 3 feet (0.6 and 0.9 m) thick.

Igneous Rocks are abundant in the Pretoria Series, specially from the top to below the Daspoort Quartzite and include both contemporaneous and intrusive types. Contemporaneous rocks belong to three separate horizons, all due to basic lavas, including tuffs and agglomerates. The highest (and least persistent) of these forms the Dullstroom Volcanic Series which lies between the basic edge of the Bushveld Complex and the top of the uppermost Magaliesberg quartzite a few miles west of Dullstroom in the Lydenburg District, but has not been met with elsewhere. The rocks occupy a belt of country averaging two miles in width, and are fine-grained to compact dark greenish basic lavas with andesitic or basaltic affinities. Abundant amygdales of quartz mark the weathered surfaces with knob-like excrescences and produce a strongly amygdaloidal structure; flow structures and agglomerate phases are also found. This horizon has undergone metamorphism through silicification and recrystallisation of the groundmass. The Dullstroom volcanic rocks show a striking resemblance to those forming the Ongeluk Series in the northern Cape Province, and those lying below the Daspoort Quartzite in the Transvaal. The approximate average thickness of the Dullstroom Volcanic Series is 1200 feet (366 m). The middle horizon forms the Machadodorp Volcanic Series and lies a little above the Daspoort Quartzite reaching from Carolina northwards through Machadodorp and continued (so as to pass Lydenburg on the east) across the Steelpoort River below Fort Burger, finally dying out a little north-west of the Motse River in Eastern Sekukuniland. Near Fort Burger this volcanic series is about 600 feet (183 m) thick, but increases considerably south-west of Machadodorp. Along this middle horizon tuffs, volcanic breccias and agglomerate are more strongly developed than the basic lavas. The majority of the included fragments consist of indurated bluish slates and of quartzites ranging from 12 inches (30 cm) in diameter down to an inch and less, their collective bulk often greatly exceeding the dirty dark bluish green matrix. North of the Steelpoort River the rocks are partly devitrified through metamorphism. The Lower horizon,—the Daspoort Volcanic Series, the most persistent of all—lies either directly below the Tunnel Quartzite (Eastern Transvaal) or a little below the Daspoort Quartzite (Central and Western Transvaal); it extends without a break from the western border eastwards through Pretoria as far as the Wilge River, where the Pretoria Series passes under Karroo and other younger formations, to reappear at Carolina, whence it continues northwards past Lydenburg (where it runs into the summit of Mount Anderson[1], but becomes thinner and finally dies out north of Ohrigstad. This group is most likely identical with the Ongeluk Volcanic Series of the Northern Cape Facies (see below). In the eastern

[1] 7489 feet (2283 m) above sea level, the highest point in the Transvaal Province.

and western Transvaal the volcanic band rests on the Ongeluk Quartzite, or on the few feet of shales above that quartzite (see Fig. 24). The Daspoort Volcanic Series is made up largely of greenish amygdaloidal andesitic lavas, carrying amygdales of glassy or saccharoidal quartz. They are sometimes abundant near the top, but are also found irregularly scattered or arranged in rudely linear aggregates at various horizons. Locally very coarse agglomerates are found (Pretoria); in the Komati River valley the series is some 800 feet (244 m) thick, but thinning down northwards. In the central Transvaal it reaches some 1200 feet (366 m) and this value is enormously increased westwards, until west of Rustenburg the series develops a thickness of several thousand feet and builds the prominent Schurwebergen. This change goes with a correspondingly great increase of the overlying ironstone bands and thus leans towards the facies which becomes fully established in the northern Cape Province; probably a series of separate flows are involved in this greater thickness.

The intrusive rocks in the Pretoria Series are represented by a large number of sheets, and much more rarely by dykes. These intrusions are essentially basic and belong to the dolerite, gabbro and diorite families. while their relationship to the invaded sediments follows clearly from the presence of chill phases and from the metamorphic influence—well seen in the shale walls. The sills are most prominent in the Magaliesberg beds, e. g. in the Belfast-Dullstroom area, where their collective thickness is at least equal to that of the associated quartzites; here occur single sheets up to 1000 feet (305 m) in thickness. Lower down in the succession they are fewer and much thinner, until they become comparatively rare and much reduced in width, below the Timeball Hill quartzites. The majority are medium-grained dark green rocks, characterised by plagioclase and augite, and often weather into scattered rusty brown spheroidal boulders. They are of pre-Karroo age and most probably from the sill phase of the norite "lopolith", a conclusion based (a) on the close resemblance in petrographical characters between the outermost portion of the norite and sheets high up in the Magaliesberg beds, (b) on the increasing number and width of the sheets as one approaches the margin of the Bushveld, and (c) on the fact that some sheets break across the highest sediments and become continuous with the margin of the Bushveld, which is often no longer a true norite, but shows doleritic and gabbroidal characters.

The thickness of the Pretoria Series has been given above.

4. The Rooiberg Series.

This group comprises a great succession of acid lavas and pyroclastic rocks, together with quartzites and shales, formerly classed as the Lower or Volcanic division of the Waterberg System, and gets its name from the Rooiberg area west of Warmbaths in the Transvaal, where the quartzites are very clearly seen. The beds are placed at the top of the Transvaal System, since—in general—their distribution follows that of the Magaliesberg quartzite and in many places marks the roof of the norite "lopolith", i. e. the outer basic ring of the Bushveld Complex, while the natural base of the true Waterberg System (formerly the so-called Upper Waterberg System) is provided by the powerful basal conglomerate (with worn pebbles of felsite and Bushveld granite) of the Waterberg sandstones. At the same time, the Rooiberg beds have not yet been identified in their proper position succeeding the Magaliesberg beds in the Potchefstroom area, where the succession lies outside the Bushveld Complex, and east-north-east of the Pilandsberg the Rooiberg group appears to lie unconformably on the lower beds of the Transvaal System.

The volcanic phase of the Rooiberg beds forms a very thick group of hard thinly bedded, flaggy, fine-grained, acid felsitic lavas, very commonly dark brown, purplish, or chocolate coloured, and cover many square miles in the Middleburg and Pretoria District, also in the Warmbaths-Nylstroom area. These lavas share in the structure of the great synclinal arrangements of Waterberg rocks north of Middelburg, but are locally much disturbed (Rhenoster Kop, Gatkop near Warmbaths) With these lavas are associated dark-coloured rhyolites, with pronounced flow structure, some amygdaloidal felsites, tuffs and extensive occurrences of agglomerates or volcanic conglomerates with many fragments and boulders up to 4 or 5 feet (1.2 or 1.5 m) in diameter, mostly of banded felsite in a reddish felsitic matrix (Rhenoster Kop). Over Sekukunis Mountains and in the Crocodile River Valley north of Brits there is much bright red granophyre, regarded as the lower crystalline layers of thick lava sheets[1]. This volcanic activity forms the first or volcanic chapter in the cycle of igneous events covering the Bushveld Complex.

Intervals of quiescence in this effusive activity led to the deposition of sediments represented by shales with thin conglomerates and quartzites. In the central Transvaal the former are for the most part interbedded in the felsites and built of material in part of volcanic origin, and form several horizons of flinty and flaggy shales or soft purple shales, up to 250 feet (76 m) thick. Here also belong the dark brownish Sterk River shales north-west of Potgietersrust. The quartzites are typically developed in the Rooiberg area, but are also well marked near the junction of the Elands and Olifants Rivers (Israels Nek and Stavoren) north-east of Pretoria, and right along the inner margin of the norite "lopolith' from near Adriaans Kop (south of Pietersburg) eastwards and southwards through Magnet Heights along the upper slopes of Sekukuni Mountains to Tautesberg north-east of Middelburg. The Bushveld granite, intrusive in the norite "lopolith", breaks into or through the roof of the latter, so that the Rooiberg quartzites are sometimes found below (Signal Hill), sometimes above the granite, as at Rooiberg; this feature accounts for the frequent irregular distribution of the sediments (specially the quartzites) of this series.

The arenaceous phase consists largely of felspathic quartzites and sandstones which are always intensely metamorphosed and often contain much felspar, which may be partly original but recrystallised material, in part introduced during metamorphism. At Rooiberg—depending upon the associated tin occurrences—tourmaline is conspicuous in these rocks. At Magnet Heights several hundred feet of very highly altered quartzite intervene between the top of the norite and the Bushveld granite (Signal Hill quartzite); locally their metamorphism is so intense that their recognition as sediments becomes very difficult (e. g. near Pokwani and west of MagnetHeights). Near Tautesberg the acid lavas resting on the norite are also very highly altered with recrystallisation.

The true thickness of the Rooiberg Series is uncertain; in the Middelburg area, where the volcanic phase is strongly marked, the series varies between 8000 and 10000 feet (2440—3050 m).

b) The Northern Cape or Griqua Town Facies.

The general distribution of the Transvaal-Nama System in the northern Cape Province and its classification within that region have been given at the beginning of section 4 (p. 72); the Rooiberg Series is not found in the Cape Province, but the three underlying groups occur in similar order, the middle and lower groups being essentially similar to the corresponding formations in the Transvaal.

[1] Daly, R. A. and Molengraaff, G. A. F. "Structural Relations of the Bushveld Igneous Complex, Transvaal." Chicago, Journ. of Geology, 32, 1924, pp. 1—35.

1. The Black Reef Series

is mainly a sandstone-quartzite group, composed of usually light coloured quartzites, grits, and gritty shales, together with subordinate conglomerates and limestones, and, when resting directly on granite (e. g. Mashowing Valley) has several feet of arkose at the base. Locally the quartzites and flagstones (near Vryburg) are darker, owing to their containing dark coloured material derived from the Pniel lavas of the Ventersdorp System; current bedding and ripple marks are common. Conglom erates are irregularly distributed and do not extend far; their pebbles consist o- quartz, chert, agate, chalcedony, granite, slates, lavas, etc. Near the top (or in Prieskaf near the base) of the series are limestones and grits like those in the Campbell Rand series above, while in Vryburg, along Zwart Rand ridge, ferruginous cherty rocks occur near the top. On the Transvaal border and near Vryburg some 50 feet (15 m) below the top of the series are blue amygdaloidal lavas. North of the Mashowing River the group is only some 30 feet (9 m) thick, but swells to about 150 to 300 feet (45.7 to 91.4 m) in the Vryburg district and in Griqualand West. South of Vryburg in the Harts-Vaal valley denudation has probably removed the beds over wide areas in Dwyka or Pre-Dwyka times, the Karroo formation often resting directly on the Ventersdorp or older rocks.

2. The Campbell Rand Series

(correlated with the Dolomite Series of the Transvaal Facies) covers large areas, and is named after the great escarpment stretching south and south-westwards from Vryburg along the right flank of the Harts-Vaal valley. This group is often nearly horizontally disposed, but thrown into broad anticlines and synclines (see Fig. 29, p. 119); it consists mainly of blue limestones, with often grey or black chert interbedded as irregular layers or in veins or along joint planes. The weathered surface is grayish or deep blackish brown owing to admixed iron and manganese, and develops the characteristic furrowed surfaces, like those of the Olifants Klip in the Transvaal dolomite. Ferruginous, hematitic and oolitic varieties are also found. Near the base shales are particularly frequent, as near Schmidt's Drift. Quartzites are occasionally found, while near Vryburg the basal portion contains fragments of lava like many of the Pniel lavas and those in the Black Reef Series. Towards the top of the limestones there are layers of ferruginous chert or jasper, similar to those forming the bulk of the succeeding Lower Griqua Town beds. Nowhere have any organic remains been found excepting a shell—probably a brachiopod—near Schmidt's Drift. The limestones have an important bearing on the ground water supply—as in the Transvaal—and carry fissures and joints widened by the solvent action of water. Some of these supply strong springs, like that at Kuruman, where the supply-fissure can be traced for 300 feet (91 m).

The thickness of the Campbell Rand series is estimated to lie between 2000 and 3000 feet (610 and 915 m).

3. The Griqua Town Series

is correlated with the Pretoria Series of the Transvaal and lies conformably on the Campbell Rand Series, with which it shares the frequently folded arrangement (Fig. 29). It is divided into these groups:—

The Upper Griqua Town Beds—banded ironstones, with very minor quartzites, sandstones and grits, but including one glacial deposit. The thickness is over 2000 feet (610 m).
The Middle Griqua Town Beds or Ongeluk Volcanic Series, chiefly built of basic lavas; well over 1000 feet (305 m) thick.
The Lower Griqua Town Beds—banded ironstones, with slates, phyllites, etc.; about 2500 feet (760 m) thick.

The **Lower Griqua Town beds** form the longest range of hills in the northern Cape Province; south of Orange River lie the Doornbergen, striking to the north-west and composed of intricately folded strata; north of the Orange River are the Asbestos Hills trending to the north-north-east and then maintained northward as the Kuruman Hills and continuing past Kuruman across the Kuruman and Mashowing Rivers to beyond Heuning Vlei; near here the strike of the beds turns more and more to the east. These hills present their steepest sides to the east where their escarpment faces the Kaap Plateau. The Asbestos-Kuruman Range is the eastern edge of a group of synclines, marked by outcrops of Ongeluk lavas.

The characteristic rocks are hard banded cherts or jaspers ("banded ironstones") coloured in various shades of yellow, brown and red by hydrated oxides of iron, black by magnetite or blue by the soda amphibole crocidolite. These rocks are often thinly bedded, with the individual layers rarely more than half an inch thick, and practically identical with the banded ironstones below the Timeball Hill quartzites in the north-eastern and northern Transvaal. Near the base the banded magnetic jaspers are interbedded with the upper layers of limestone in the Campbell Rand series, a transition comparable to that sometimes found in the Transvaal Province (Pretoria).

The lowest strata of the Griqua Town beds are often sharply bent and broken, though the underlying limestones remain nearly horizontal, while higher up the banded ironstones are again little disturbed and dip conformably with the limestones. This feature is repeated many times specially near Daniels Kuil, e. g. on Ramaje's Kop, and over the Maremane anticline. The bent strata are seen to lie in hollows in the limestone originating as solution cavities into which the overlying ferruginous beds collapsed. The extreme stage of this process occurs in the Maremane anticline —a broad limestone area north of Postmasburg showing numerous outliers of the Lower Griqua Town beds—as the Blink Klip breccia, named from abundant small crystals and spangles of specular iron causing a striking glittering appearance. The fragments are invariably angular and belong to those types which occur near the base of the series, but are enriched in oxide of iron. The lower parts of the breccia carry smaller fragments and have a higher proportion of more ferruginous matrix than the upper, while in many cases an increase in the size of the fragments upwards is shown. At Blink Klip Kop itself, there is an extensive irregular cave-like opening on one side of the Kop, made by natives in search for specular iron, and the floor of this hollow lies some 80 feet (24 m) below the level of the surrounding Campbell Rand limestones.

The soda amphibole crocidolite is widespread in delicate blue compact heavy very tough layers and in cross fibre seams of blue asbestos—both varieties being interbedded. The former is a kind of mass fibre, built of countless minute non-oriented fibres matted together. It is often found in many pebbles-like detrital lumps showing a highly characteristic polished black weathered surface. The second variety is true asbestos and is the "Cape-Blue" of commerce. Both forms are also known in the banded ironstones of the Transvaal Facies. Due to oxidation of the ferrous iron and its replacement (including part or all the accompanying soda, magnesia, etc.) by silica, the blue crocidolite passes through brown and golden yellow tinted stages into almost white fibrous quartz. This is the so-called "Tiger Eye" and "crocidolite" of the jeweller, which takes a high polish and is used as a semiprecious ornamental stone.

Quartzites, sandstones and grits are very restricted and do not persist over wide areas. Limestones now and then occur in the lower part, but their chief horizon is about 100 or 200 feet (30.5 or 61 m) below the Ongeluk Lavas, where they resemble the more ferruginous varieties of the Campbell Rand limestones.

The most remarkable formation in the Griqua Town Series is the Glacial Deposit, which is found at many places from the Orange River northwards to Madebing on the Mashowing River in Bechuanaland, the known outcrops being scattered over some 8000 square miles (20700 qkm) of country. The horizon[1] lies a little below the base of the overlying Ongeluk Lavas, from which the glacial deposit is separated by some 30 feet (9.1 m) of shales and jaspers, though along the Kuruman river it is directly overlain by the lavas. Near Koegas north of Prieska the tillite is 10 feet (3.05 m) thick, but may become nearly 100 feet (30.5 m) thick in the Hay division. The deposit is blue or grey, but often red or brown through hydrated ferric oxide; it has boulders and pebbles scattered through it, independent of their size, and they lie in a fine-grained calcareous and siliceous matrix. The boulders and pebbles often show one or more sides flattened and striated in a manner characteristic of stones found in glacial tills. They consist of crystalline limestone, chert, occasional quartzites and grits, but granite schist and diabase do not occur, though thin sections of the matrix show felspar chips and mica flakes, probably of granitic origin. Numerous nodules of chert—forming true pebbles and also striated—are met with in the tillite; they are unlike any yet found elsewhere in South Africa.

Though no locality has yet been found where the deposit rests unconformably upon a striated surface, its general character and the shape of the scratched boulders resemble those of the tillites in the Table Mountain Series and the Dwyka.

The **Middle Griqua Town beds** or Ongeluk Volcanic Series rest upon thinly bedded hard shales or upon the tillite, with perhaps an unimportant slight unconformity. This group consists of fine-grained greenish lavas of andesitic type, with occasional layers of red and grey jasper and chert, and greenish flagstones; volcanic breccias and tuffs are sometimes found. Broad shallow synclines of them occur in the divisions of Hay and Kuruman (e. g. Witwater syncline, Ongeluk syncline).

The devitrified matrix contains minute feathery microlites of augite, or hornblende, small felspars, and small crystals of enstatite, etc.; in the amygdaloidal forms chalcedony, calcite and chlorite fill the steam holes. In the Mashowing and Kuruman Rivers some lava flows exhibit a kind of "pillow structure" due to large blocks of lava, separated from one another by darker coloured material, and up to 8 feet (2.4 m) wide.

Some of the lavas are accompanied by brittle jaspers or cherts, often brilliant red, but also greenish, black or gray, and in places carrying yellow garnets; this colouration is due to hydrous oxide of iron, epidote, or magnetite.

Collectively the Ongeluk closely resembles the Daspoort Volcanic Series of the Transvaal Facies.

The **Upper Griqua Town beds** occur in the north-west part of Hay and the south-west part of Kuruman, resting conformably upon the Ongeluk Lavas, and unconformably overlain by the Matsap beds of the Langebergen. They are built of the slaty rocks, phyllites, some quartzites, blue limestone and red, black and brown magnetic cherts or jaspers, very like the thicker bedded jaspery rocks of the Lower Griqua Town beds. Surface deposits conceal them over large areas in the Kuruman division.

Comparisons between the Transvaal and Griqua Town Facies.

While no fundamental differences in lithological characters and sequence distinguish these two facies in respect of the Black Reef and Dolomite Series, there are marked distinctions in the stratigraphy of the Pretoria Series. In the northern Cape Province the latter is threefold—a great succession of basic lavas separating

[1] The position of this tillite shows a very close analogy to that of the conglomeratic Ongeluk Quartzite below the Daspoort Volcanic Series (Ongeluk Series) in the Transvaal (See above).

two essentially similar successions of banded ironstones, but in the Transvaal the series is much more variable and subject to great and rapid lateral changes in facies. From the Pretoria type section westwards the Daspoort Volcanic Series increases enormously in thickness, while the overlying ironstone band becomes several hundred times thicker, than it is at the capital, and at the expense of the succession above it. At the same time, the Magaliesberg Quartzite and the Daspoort Quartzite thin down towards the west, while near the base an additional banded ironstone becomes gradually established, with an increasing thickness towards the west. The general trend of these variations appears to justify the following tentative correlation:

Griqua Town Facies	Transvaal Facies.
Upper Griqua Town Series.	Ironstone Band and overlying succession.
Middle or Ongeluk Volcanic Series.	Daspoort Volcanic Series (Amygdaloidal Andesite).
Lower Griqua Town Beds.	Banded Ironstones below the Timeball Hill Quartzite and the beds above up to the base of the Amygdaloidal Andesite.

The great stretch of country between the western Transvaal border and the Molopo River—some 140 miles (225 km) wide—over which the system is not exposed, leaves the above correlations uncertain, but the great variation in conditions of sedimentation implied by the Griqua Town Facies is consistent with the striking changes effected in the Transvaal over much shorter distances, as illustrated e. g. by the marked difference between the number and thickness of the Magaliesberg quartzites established between Pretoria and Belfast within less than 90 miles (145 km) of strike, or by the transition of over 1000 feet (305 m) shales below the Timeball Hill quartzite into banded siliceous ironstones over the Steelpoort River valley, completed in less than 40 miles (64 km) of strike.

c) The Western Cape or Nama Facies[1].

At the beginning of this section reference has been made to the distribution of this facies and the general correlation given of its subdivisions, but on the exact stratigraphical significance of some of these the data are incomplete.

1. The Black Reef Series

is represented by the Nieuwerust Series, found in several detached masses over the western parts of the Cape Province between the Orange and Olifants Rivers near Van Rhynsdorp, but so far not known from the country south of the Olifants River. A narrow belt of slightly inclined but much faulted rocks lying unconformably upon gneiss in northern Namaqualand and described as the Steinkopf Beds also belong to the Nieuwerust Series. In Namaqualand and Van Rhyns Dorp the Nieuwerust Series underlies the Malmesbury beds. The Nieuwerust Series is named after a village situated north-north-west of Van Rhyns Dorp and consists of quartzites, arkose, hard shaly beds, and conglomerates. At several places the arkose, or a conglomerate with an arkose matrix, rests upon a worn surface of gneiss, and is composed of pieces of felspar and quartz derived from the Namaqualand granite and gneiss, pebbles of which are locally abundant. Though usually gently inclined, the beds have been affected by a series of faults with northerly and north-westerly trend and the succession is repeated due to the Groot Riet, Lang Dam and Koap Faults and the south-east end of the Byzondermeid fault. On Draai Hoek blue slightly

[1] For details see A. W. Rogers: "The Nama System in the Cape Province". Trans. Geol. Soc. S. Africa, 15, 1912, pp. 31—50.

felspathic quartzites rest upon gneiss and dip under shales and limestones (both placed in the Malmesbury Series); followed to the south these bluish quartzites pass into coarse red felspathic grits, further south interbedded with typical arkose. The Nieuwerust beds appear to thicken southwards on Bukfontein, Byzondermeid and Roodekloof by the addition of grits and arkoses, but south of Roodekloof they become finally much reduced in thickness.

Near Groot Graafwater the Nieuwerust Series is nearly 500 feet (152 m) thick, and about 200 (61 m) on Byzondermeid and Roode Kloof, and not more than 70 feet (18 m) further south on Banker.

With the

2. Dolomite Series

are correlated the Malmesbury beds (including the Aties group), and the Cango Series, but in some of these there is a considerable development of argillaceous besides calcareous rocks. Just south of Kamiesberg there is clear evidence that shales and limestones, identical in character with those of the Aties Group and included in the Malmesbury Beds, rest conformably upon the Nieuwerust Beds, the highest strata in the sequence being the Ibiquas, but an unconformity certainly exists between the Malmesbury and Ibiquas Beds in the division of Van Rhyns Dorp and in the districts to the south. While in Little Namaqualand thick dolomitic limestones rest on the Nieuwerust beds, the former beds, through an important change in facies which becomes more marked southwards, pass into an argillaceous and arenaceous group—the Malmesbury beds of the Cape Province (e. g. round Malmesbury, Cape Town etc.). East of the Cape Peninsula, however, in the Oudtshoorn and Humansdorp divisions, there are again limestones (Cango and Hankey limestones), which may be part of this series.

The **Malmesbury Beds** form a variable group of quartzites, felspathic quartzites, flagstones, shales, slates, micaceous slates and phyllites, limestones and cherty beds. The succession varies greatly from place to place, the quartzites and limestones being inconstant. The limestones are black, blue or white rocks, thoroughly crystalline and not accompanied by chert, but sometimes associated with soft black shales, weathering often to a white, pink or yellow clay (Aties south of Van Rhyn's Dorp); the dark limestones, when broken up, smell of sulphuretted hydrogen. No organic remains have been found in these rocks. The most abundant rock in the Malmesbury Beds is a blue arenaceous clay-slate, or very fine-grained argillaceous quartzite with imperfectly developed cleavage and a lustrous appearance on its cleavage planes, caused by small flakes of white or yellowish mica. These rocks are usually altered to a depth of many feet into white, yellow, or brown sandy or clayey matter. The beds are nearly always dipping at high angles and repeatedly folded; much of the series as it occurs over the divisions of Malmesbury, Piquetberg, Paarl, Stellenbosch, Somerset West, and over the Cape Peninsula, or in the Tulbagh valley is of this character. Near here the Malmesbury beds are cut off by the great Worcester Fault, the downthrow of which is over 12000 feet (3658 m). Thin bands of crystalline limestone are found interbedded with the slates near Piquetberg, Vogel Vlei and elsewhere. Local phases of very micaceous slates and sericitic phyllites pass into impure quartzites (Mooreesburg and Tigerberg). Schists containing ottrelite occur in thin bands near the junction of the Malmesbury Beds with the unconformably overlying Table Mountain Series near Worcester and north of Swellendam.

The series is also represented in Mossel Bay, George (black slates and quartzites penetrated by masses of granite and many granitic veins) and near Port Elizabeth (crystalline limestones, slates and quartzites at the Maitland Mine).

The Malmesbury beds have been invaded by acid igneous masses, mainly granite and gneiss, and strongly metamorphosed (e. g. Seapoint near Cape Town, etc.)

Fig. 25. Section through the Cango and Zwartebergen, 11 miles (17.6 km) east of Prince Albert Village. Distance 20 miles (32 km). Vertical and horizontal scales are the same.

Cango series: 1. Conglomerate. 2. Slates. 3. Limestone. 4. Porphyroid.
5. Intrusive dolerite dyke (altered). 6. Table Mountain series. 9. Dwyka series.
7. Bokkeveld series. 8. Witteberg series.
10. Ecca series. 11. Uitenhage series.

The true maximum thickness of the Malmesbury beds is not known, but it is at least several thousand feet in the division of Van Rhyns Dorp. On Byzondermeid it is estimated at some 3000 feet (914 m).

The **Cango Beds** lie east of the Cape Peninsula near the northern boundary of Oudtshoorn on the southern flank of the Zwartebergen and show obvious points of resemblance in lithological characters with the Nama facies of the western Cape, but little is so far known of their true succession. The beds occur over a lenticular area some 70 miles (113 km) long from east to west and up to about 9 miles (14.5 km) wide, built up of conglomerates, quartz-felspar grits, quartzites, slates, limestones without chert and arkoses, and limited unconformably on the north by the Table Mountain Series. These beds usually have high southerly dips and are thrown into isoclinal folds (Fig. 25), giving an increased apparent thickness; the true succession is uncertain and the base has not been found. There are several varieties of conglomerates, differing in the nature of their pebbles and in the degree of shearing, locally so intense as to obscure the exact limits between matrix and pebble. Many bands of limestone also occur, some of great thickness, and lenticular in shape. One, near the south end of the Zwartberg Pass is 15 miles (24 km) long and has the famous Cango Caves, due to the solution of the limestone and breaking away of roof and sides. The band carrying these caves is some 1800 feet (548 m) thick, a dark grey crystalline limestone, locally oolitic. The thickness of the Cango Beds is probably not less than 10000 feet (3050 m). The

3. Pretoria Series

is represented by the Ibiquas Beds, and the French Hoek Beds. In the division of Van Rhyns Dorp and in the more southerly area an unconformity separates the base of the Ibiquas Beds from the underlying Malmesbury Series.

The **Ibiquas Series** is seen in the western part of the division of Calvinia and in the north-eastern portion of that of Van Rhyn's Dorp; in the little disturbed country east of the Koap Fault on Byzondermeid the beds occur in a shallow syncline, where the dip shows little difference from that of the underlying Malmesbury beds, but further south conglomerates and grits trend slantingly across the strike of the Malmesbury beds, until they almost rest upon the quartzite and arkose of the Nieuwerust Beds. The Ibiquas beds also occupy a very wide area in the valley of the Zout River and between that river and the Bokkeveld escarpment. The group consists of sandstones, slates, arkoses, grits and conglomerates. At or near the base is a thick development of conglomerates carrying pebbles and boulders of quartzite, crystalline limestones, phyllites, gneiss, granite and quartz porphyry. The included limestone fragments in colour and general character recall some of the limestones of the Malmesbury Beds. The slates in the Ibiquas Series show very little difference, if any, compared with the Malmesbury slates. The shales and sandstones occur on the steep escarpment of the Bokkeveld Mountains and in the Doorn River Valley and are somewhat like those of the Bokkeveld beds, but the thick sandstone group characteristic of the latter, is wanting in the Ibiquas beds. Many sandstones throughout the latter show very well preserved ripple marks indicating shallow water conditions of sedimentation, and locally there are abundant large tracks and worm castings. In the Van Rhyns Dorp area there is a peculiar felspar grit with a dark grey shaly or slaty matrix through which are scattered small pebbles of quartz, felspar and other material, up to one quarter of an inch long. Though the Ibiquas beds are in part repeated by folding, they are several thousand feet thick.

In the Verloren Valley in the Piquetberg division certain reddish shales and sandstones are assigned to the Ibiquas beds, since they contrast strongly with the sericitic slates of the Malmesbury series, in contact with them. Near Honig Berg, also in this division, are several outcrops of the Ibiquas Series, consisting of red conglomerates carrying pebbles up to 20 inches (50 cm) in diameter, of reddish quartzitic rocks resembling some of the Malmesbury beds in that area.

The term **French Hoek Beds** is given to a series of conglomerates, arkoses, pebbly grits and slates found at French Hoek, or between that point and Klapmuts, or on Klapmuts Hill. These beds include a coarse sheared conglomerate containing rounded boulders of grits, slates, quartzite, quartz porphyry, granite, etc. Some strata, in contact with quartz porphyry, are built of cleaved grits and sheared arkoses, resembling sheared quartz porphyries; the coarse felspathic material building the arkoses is probably derived from such acid rocks.

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5. The Bushveld Igneous Complex.

By

A. L. Hall.

a) Distribution and General.

(See Fig. 26 = Plate III)

The term Bushveld Igneous Complex (Bushveld Plutonic Series of Molengraaff[1]) is applied to a genetically connected suite of volcanic and intrusive rocks as probably the most extensive petrographical province on record. It occupies a roughly oval area in the Central Transvaal (see Fig. 26, Plate III) aligned along a direction from E.N.E. to W.S.W. some 280 miles (450 km) long and with a maximum width of about 150 miles (240 km), extending from the neighbourhood of Lydenburg in the east westwards to Zeerust, and from Pretoria northwards to Potgietersrust, though here and there portions are concealed by overlying younger formations of the Waterberg System and the Karroo System. The alignment referred to is perhaps genetically connected with a pre-existing line of weakness determined by the direction of schistosity in the ancient schists, which probably once occupied the area now covered by the Bushveld Complex, and are represented by e. g. the Murchison Range and the schist belt of Mount Maré.

The intrusive phases of the Complex were emplaced more or less along the top of the Pretoria Series as the floor and along the basal portion of the Rooiberg Series as the roof, in such a way that the load of the intruded material, in particular that of the earlier basic mass, depressed the underlying Pretoria Series downwards; hence for the greater part all round the margin of the Complex the quartzites and shales of the floor dip from all sides into the Complex (see Fig. 27). This inclination becomes less and less further away from that margin. Owing to this arrangement and to the prevalence of resistant quartzites the Complex is for the most part surrounded by relatively high ground, such as the Magaliesberg in the Central and Western Transvaal on its southern and the Strydpoort Range on its northern side. The general configuration thus corresponds, broadly speaking, to an irregular saucer, of which the interior portion is occupied by the various members of the Complex, while the rim is built of radially inward dipping sediments.

E W

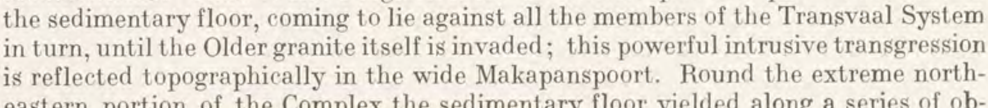

Fig. 27. Generalized Section across the Bushveld Igneous Complex in the Eastern Transvaal. S. Shales (Pretoria Series). Q. Magaliesberg Quartzite (Pretoria Series). N. Norit, Pyroxenite, etc. G. Red or Bushveld Granite. R. Quartzites etc., (Rooiberg Series). F. Felsites, etc. Length of Section: 30 miles (48 km).

Locally the emplacement was accompanied by powerful and complex tectonic modifications. Thus round Potgietersrust the earlier plutonic phase broke across the sedimentary floor, coming to lie against all the members of the Transvaal System in turn, until the Older granite itself is invaded; this powerful intrusive transgression is reflected topographically in the wide Makapanspoort. Round the extreme north-eastern portion of the Complex the sedimentary floor yielded along a series of oblique faults coinciding in direction with the principal tectonic alignment of the Murchison Range, while round Pretoria the group of extensive faults similarly express the relief from the great strain resulting from the emplacement of the great thickness of basic rocks.

[1] "Géologie de la République Sud-Africaine du Transvaal." Paris, Bull. Soc. Géol. de France, Sér. 4, 1, 1901, pp. 13—92.

b) Sequence of Events.

The cycle of igneous activity begins with an important Volcanic Phase, represented by the great succession of contemporaneous rocks grouped under the general term felsite, but including an important development of volcanic breccias, tuffs, agglomerates and other pyroclastic rocks. These are described in connection with the Rooiberg Series, and their association with several horizons of interbedded shales and fine-grained quartzites indicates that periods of contemporaneous volcanic activity were separated from one another by comparatively short intervals of sedimentation, during which shales and quartzites were laid down. These intervals appear to have been long enough to allow for some denudation of the volcanic rocks which are represented by pebbles of felsite in the conglomerates of the Rooiberg Series; the fine-grained quartzites also suggest that some of their material was derived from disintegrated and finely comminuted felsite. This volcanic phase led to a maximum thickness of extrusive rocks of about 10000 feet (3050 m), but there is no reliable information where the main centre or centres of eruptive activity were situated. Closely associated with the felsite are a series of bright red medium grained granophyres, which in some places appear to grade upwards into felsite, while elsewhere showing a sharp contact against the latter. It has been suggested[1] that the consolidation as granophyre is due to the intrusion of felsitic magma into its own superficial quickly chilled and solidified phase.

The second or Plutonic Phase is twofold and comprises an earlier basic and a later acid phase.

The earlier phase is almost wholly basic and essentially a Norite Group of enormous thickness, though including a series of basic or ultrabasic types, as explained below. This was emplaced between the top of the Magaliesberg (Pretoria Series) beds, and the base of the Rooiberg Series in the form of a stupendous sheet, with spatial relationships in some respects like those of a Lopolith[2]. This group forms the outer portion of the Bushveld as a marginal basic facies, and throughout the western, central, eastern, and north-eastern parts of the Transvaal its floor is in direct contact with the Magaliesberg quartzite or with a thin body of shales overlying that formation. Near Potgietersrust, owing to the intrusive transgression already referred to, the base of the norite lopolith cuts across successively lower horizons of the Transvaal System until it comes to lie against the Older Granite. The upper limit of the norite lopolith is for the most part in contact with the felsites or quartzites of the Rooiberg Series, e. g. in the north-eastern Transvaal.

Subsequent to its emplacement the great norite sheet underwent thorough differentiation, mainly on gravitative principles (see below).

Probably pari passu with this earlier plutonic phase the floor and upper portion of the underlying Pretoria Series were invaded by a large number of more or less basic sills; these are less basic than the prevalent type of norite and may represent the original magma prior to its differentiation into felsite, norite and granite. Their close connection with the norite lopolith as the sill phase of the latter follows from their local direct continuity with the main mass of the basic margin of the Bushveld from their general similarity in petrographical characters (in some localities) with the lowermost portion of the lopolith, and lastly from their mode of distribution, which shows a marked decline in the number and dimensions of the sills as one descends into the sedimentary rim of the Bushveld. These rocks are referred to in section 4 above.

[1] DALY, R. A. and MOLENGRAAFF, G. A. F.—"Structural Relation of the Bushveld Igneous Complex, Transvaal." Journ. of Geology, 32, 1924, p. 31.

[2] GROUT, F. F.—"The Lopolith, an igneous form exemplified by the Duluth Gabbro." Amer. Journ. Science. 46, 1918, p. 521.

The later incident of the Plutonic phase is the Red or Bushveld Granite, cutting the earlier norite, as well as the Volcanic Phase (including its granophyric element) by dykes, sheets and stocks of coarse red granite. The latter occupies, broadly speaking, the central areas of the Bushveld and was locally emplaced along the contact between the top of the Norite lopolith and the overlying Rooiberg quartzites or was intruded into the latter. Several powerful dykelike masses of Red granite in the Steelpoort River valley (e. g. near Magnet Heights) as well as some minor masses in the Dwars River area rising up through the norite prove that the later plutonic phase is intrusive in the earlier basic phase, a relationship forcibly emphasised by a striking plutonic breccia found a little east of Magnet Heights[1]; its large angular inclusions of norite blocks show that the norite had thoroughly solidified prior to the intrusion of the Red Granite.

The Bushveld Complex thus indicates a case of the differentiation of a vast and deep seated magma into a salic pole, which solidified without a roof as compact felsite, into a plutonic norite phase having the salic pole (or its associated sediments) as roof, and a final plutonic phase of red granite, solidifying under or within the same roof—the whole petrographical province being floored by the Pretoria Series of the Transvaal System.

The conditions of differentiation and consolidation were remarkably uniform, since exactly similar associations of rock types are repeated all round the Complex and distributed in corresponding levels in the "lopolith", including extreme ultrabasic segregations like magnetite and rocks rich in chromite.

c) Principal Rock Groups and their Distribution.

Although the Bushveld Complex comprises a very large variety of rock types in detail, the great majority fall into one or other of the groups shown in the following table No. I, which also summarises the preceding information in concise form (See page 99).

The Sill Phase is very marked in the Pretoria Series and consists mainly of basic rocks; these, together with the petrographically very similar basic dykes are referred to in section 4, page 87.

The Volcanic Phase is essentially felsitic and is discussed in connection with the Rooiberg Series (section 4, page 87).

d) The Earlier Plutonic Phase or the Norite Group

is the most conspicuous element of the Complex and distributed as a basic margin more or less all round the Bushveld. In the north eastern Transvaal it attains its maximum development as a broad band up to 16 miles (25.75 km) wide, covering several hundreds of square miles in the Pietersburg and Lydenburg Districts, and extending from north to south over some 112 miles (180 km); in Sekukuniland (Lydenburg District) it gives rise to a series of rugged hills and ridges, among which the Lulu Mountains are the most prominent. Towards the south the norite belt runs up the valley of the Steelpoort River, but narrows down considerably, until, near Wonderfontein on the Delagoa Bay Line, it passes under the Karroo rocks. The sheet-like character of the Norite Group is well seen north of Middelburg, where the erosion over the Bloed River valley between Stoffberg and Tautes Hoogte has cut through the overlying roof into the underlying norite, the contact between these formations being continued almost due westwards, after the manner of a gently inclined succession of sediments.

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[1] Discovered by Dr. F. E. Wright during the excursion of the Shaler Memorial Expedition in 1922.

Table I. Bushveld Igneous Complex.

	External to Bushveld Proper	Bushveld Igneous Complex Proper		
			Plutonic Phases.	
Phases	Sill Phase	Volcanic Phase	Earlier Basic	Later Acid
Emplacement	In Pretoria Series	No roof	Between a floor of Magaliesberg Quartzite and a roof of Rooibreg Series	In Rooiberg Series or between it and the earlier basic phase
Dominant Rock Types	Dolerite, Gabbro etc.; mainly sills, but possibly also including numerous dykes (e. g. De Kaap Valley etc.)	Felsite, tuffs, agglomerate, rhyolite, etc.	Norite, bronzitite, pyroxenite, anorthosite, peridotite, serpentine, etc. with concentrations of chromite and magnetite	Mainly coarse grained red granite
Distribution of Phases	Outside Bushveld		Marginal within Bushveld	Centrally within Bushveld
Thickness	From 1200 feet (365 m) downwards	Maximum 10000 feet (3000 m)	From 18000 feet (5480 m) downwards	?
Stratigraphical Position	Post-Pretoria Series and Pre-Waterberg	Rooiberg Series	Post-Rooiberg Series and Pre-Waterberg	Post-Rooiberg Series and Pre-Waterberg

From Wonderfontein westwards the basic margin of the Bushveld is concealed by rocks of the Waterberg and Karroo Systems, from below which the norite group reappears near Pretoria, to continue westwards for some 160 miles (250 km) to the neighbourhood of Zeerust. In this portion of the Bushveld the width and thickness of the basic group is distinctly less and though a very large area is occupied by it round the western end of the Complex, this is largely the result of the low dip of the floor an the shallow depth of the norite sheet.

Along the northern edge the distribution is again strictly marginal, but owing to the intrusive transgression near Potgietersrust, referred to above, a narrow belt of the norite group extends from that locality northwards down the Magalakwin.

There is thus little doubt that the thickness of the norite lopolith decreases considerably from east to west. In the former area (e. g. Sekukuniland) the magma pool had its maximum depth, while in the western Transvaal it was much shallower, so that in places denudation has exposed the underlying floor. Now and then extensive masses of highly altered sediments, largely of the Pretoria Series, have been caught up and are now surrounded by the plutonic phases of the Complex, e. g. in the Crocodile River valley north of Brits in the Western Transvaal.

A very conspicuous "rifting" or pseudo-stratification is a persistent and most remarkable feature in the norite margin of the Bushveld, and becomes more and more pronounced in proportion as one approaches the sedimentary floor, while in the uppermost portion of the lopolith it is almost lost. This rifting is met with more or less all round the Complex, but finds its most striking expression topographically and petrographically in the Lydenburg District, specially in Sekukuniland and round Malips Drift along both sides of the Olifants River. Here are a series of very sharply defined linear features, continuing for miles, with regular escarpments facing to the east and dip slopes facing to the west, thus recalling in a most striking manner the effects of erosion on a succession of slightly inclined sediments. North of Pretoria the clear cut features known as the Pyramids illustrate the same "rifting". These linear elements go with slight petrographical variations, and afford no definite indications of having originated as separate intrusions. Their "dip" conforms closely to that of the underlying Pretoria Series in amount and direction and no doubt depends upon the disposition of the passive sedimentary floor. When combined with two sets of major joint planes this pseudostratification tends to produce very regular Cyclopean structure in places (Malips Drift).

The extraordinarily pronounced rifting is most likely due to gravitational differentiation, consequent upon the emplacement of a vast body of magma upon a more or less horizontal sedimentary floor. Layers of different composition were gradually established in such a way that—in general—the lighter material was concentrated nearer the top and the heavier portion nearer the floor, but not at the very bottom, since the pure gravity effect is disturbed by other factors, such as viscosity, a relatively cold floor, etc. At the same time the weight of the lopolith pressed down the floor very gradually and the consequent sinking of the sediments continued over a long period of geological time and may even have been maintained through the Red Granite phase into the Waterberg period of deposition, as probably indicated by the local rifting of the Red Granite itself in the Zaaiplaats area near Potgietersrust and by the synclinal disposition of the Waterberg strata north of Middelburg.

As a result of this pronounced and persistent pseudo-stratification it is almost permissible to speak of "horizons" within the norite body and this is specially justified in the eastern portion, since here the magma pool was deepest, and therefore differentiation and rifting had the best chance of reaching their maximum effect. In the Western Transvaal, on the other hand, where the basin was specially shallow, pseudo-stratification is much less pronounced and differentiation, on the whole, not so striking, or at least on a distinctly smaller scale.

e) The Major Belts of the Norite Lopolith.

The basic plutonic phase shows a series of broad zones each characterised by a certain variety or varieties of petrographical types. These zones are in the nature of the case not sharply defined, yet each develops certain predominant phases, which are either absent or quite subordinate in the other zones. Bearing in mind the variation in thickness of different portions of the Lopolith, emphasised above, it is natural to find such broad zones best defined in the eastern or deepest end of the basic phase (Sekukuniland), where rifting is most pronounced and differentiation has been most thorough. From the base upwards these petrographical belts are as follows:—

1. **The Basal or Chill Zone.** This is a very narrow zone forming the lowest portion of the lopolith and resting directly on the sedimentary floor of the Pretoria Series— usually Magaliesberg quartzite, but now and then crystalline hornfels, originating as intensely metamorphosed shale of the Pretoria Series. The phase is well developed in north-eastern Sekukuniland, but is often not clearly traceable, owing to the temperature of the floor having been raised high enough to prevent marked chilling, or else there has been too much assimilation of sedimentary material, and owing to other causes. Thus in the Potgietersrust area along the intrusive transgression above referred to, the extreme outer edge of the lopolith is still fairly coarse, owing to the high temperature to which the floor was raised, while meta-

somatism and assimilation have produced a marginal series of locally contaminated rocks, e. g. at Potgietersrust, and northwards on Witrivier, Tweefontein and Drenthe, specially marked where the transgression brings the norite mass in direct contact with the dolomites of the Transvaal System; on the other hand in the Malips Drift area in the north-eastern Transvaal, pure igneous rocks extend right down to the Magaliesberg quartzite and have passed into a zone of dark evenly fine-grained basic rocks, having a width of several hundred feet and a mineralogical composition essentially similar to that of the common types forming the central portion of the norite group.

2. **The Transitional Zone.** The next petrographical belt, where it is best defined, i. e. from Malips Drift southwards to the Motsi River has a variable surface width up to about 2 miles (3.2 km) and consists for the most part of somewhat basic bronzitite, with, on the whole, well-defined narrow zones of dark greenish pyroxenite. The latter occur as linear features along which conspicuous escarpments and dip slopes display pseudostratification and Cyclopean structure, sometimes with striking regularity, e. g. Jachtlust and Zeekoegat near Malips Drift. Varieties containing disseminated grains of chrome iron are occasionally found, and locally one meets short narrow lenticular aggregates of the same ore, but these features are quite subordinate compared with the next phase.

3. **The Critical Level of Differentiation** or the Zone of Heavy Components. This is petrographically the most remarkable as it is economically the most important belt of the norite "Lopolith", and is referred to as "Critical" since magmatic differentiation has given rise to a large number and great variety of rocks showing extreme contrasts in composition, so that the factors of such differentiation (e. g. temperature relationship, limited miscibility, viscosity, possibly liquation, etc.) were in circumstances of critical adjustment. In Eastern Sekukuniland this belt attains its maximum surface width of about 3 miles (4,8 km), which narrows down sensibly in the southerly or north-westerly direction; it is also well represented west of Pretoria between the Hartebeestpoort Dam and Brits Station, as well as further west in the Vlakfontein area near the Pilandsberg, while apparently in the Potgietersrust area this zone is not typically developed. Rocks rich in olivine, and bands composed almost wholly of chrome iron are highly characteristic of the Critical Level, which is made up of a succession of many widely different types, ranging from nearly pure felspar rocks downwards to thoroughly ultrabasic varieties. Here belong anorthosites, pyroxenites, bronzitites, diallage norites with or without disseminated chrome iron, dunites, serpentines, bands of chromitite and other basic or ultrabasic modifications. The economic importance of this zone lies in the recent discovery of scattered particles of native platinum in the dunites—Dunite Reef—and of the platiniferous sulphides in pseudoporphyritic diallage norites—Merensky Reef—(See under Economic Geology, pages 174, 175).

In general the dunites form highly inclined (sensibly vertical) cylindrical or pipe-like bodies tapering slightly downwards, and of very restricted extent along the strike, while the chromite bands, together with the diallage-norites, anorthosites, etc., for the most part extend along the strike with remarkable persistence for many miles in the same general position relative to the preceding phase below and to that which follows above; hence their distribution can be described as following a pretty well defined horizon, notwithstanding the fact that these rocks are not part of a sedimentary column. Thoroughly leucratic rocks rich in plagioclase are very often intimately associated and in direct contact with highly melanocratic basic rocks; thus anorthosite—forming bands from a few feet (Jachtlust near Malips Drift) to a hundred and more thick (Der Brocken west of Lydenburg) — in many places overlies dark coloured chromite bearing platiniferous diallage norite, or separates a series of bands of chromitite. Such associations have been traced without a break for many miles through the Lydenburg District and reappear with identical petrographical details in the Central and Western Transvaal—invariably accompanied by more or less well defined pseudostratification, hence in conformity with the dip of the surrounding (underlying) girdle of sediments. The remarkably close association between the light anorthosite and its underlying heavy diallage norite is probably not accidental but has genetic significance and may depend upon a lack of adjustments in some of the factors of magmatic differentiation alluded to (liquation of partially miscible liquids ?).

Pegmatites are rare not only in this zone but also elsewhere within the norite, but a coarse hornblende pegmatite and a very coarse quartz tourmaline pegmatite are not uncommon close to the horizon of the platiniferous diallage norite, e. g. on Maandagshoek, Dwars River, etc.

4. **The Main Belt** usually makes up at least half, sometimes even considerably more than half, the entire norite mass, and in Eastern Sekukuniland occupies a surface width of some 9 miles (14.4 km), reduced to about 3 miles (4.8 km) in the Central Transvaal and roughly 4 miles (6.4 km) in the Potgietersrust area. It is on the whole little differentiated and characterised by a much greater petrographical uniformity and may consist of many hundreds of feet of the same type of norite. In the eastern Transvaal it includes most of the hilly country associated with the basic margin of the Complex, i. e. the entire ranges or ranges of the Lulu Mountains, and the highly sculptured country between Roos Senekal and Magnet Heights, while in the Central Transvaal it embraces the Pyramid line of hilly ground north of Pretoria and that of Zwartkopjes round Brits. Forming the more central horizon of the "lopolith", pseudostratification, though still traceable, is less pronounced, and through spheroidal weathering, often on a rather large scale, the hills are rugged and strewn with large hummocky blocks which develop characteristic almost black surfaces of weathering; rather tall sharply pointed conical hills also occur and give rise locally to a kind of island landscape, e. g. Moodimoolah in Eastern Sekukuniland. In the main belt the olivine bearing types, the chromite bands, the anorthosites, and other highly specialised rocks of the Critical Level are quite subordinate or absent over many miles of strike, but almost at its upper limits, it includes a striking development of rocks rich in magnetite or of practically pure magnetite rocks; in contact with the latter are bands of anorthosite, an association probably once more genetic like that already noted within the Critical Level; here e. g. belong the phenomenal magnetite deposits of Magnet Heights west of Lydenburg, those of Roos Senekal, of Magnet Kop, as well as others in the Western Transvaal. Such bands may become up to several feet or even yards thick.

5. **The Upper Zone** extends from approximately the principal horizon of magnetite deposits upwards to the roof, which is for the most part supplied by the quartzites and felsites of the Rooiberg Series. Since the latter are highly resistant to weathering agents and sometimes thoroughly indurated through intense metamorphism, the upper limit of the "Lopolith"—where it has not yet been deroofed—is sometimes very sharply defined by a prominent line of high ground, e. g. along the escarpment of Sekukuni Mountains from Magnet Heights to Middelburg, or along the so-called Granite and Felsite Ranges due west of Potgietersrust. The Upper Zone has a width variable within wide limits, and reaching a maximum of about 2 miles (3.2 km) in the Magnet Heights area; it is thus distinctly narrower than the Main Belt. Like the latter, however, the Upper Zone is, on the whole, fairly uniform in composition, but collectively the rocks are less basic; as one passes upwards towards the roof they become somewhat less melanocratic and locally may assume a slight pinkish tinge due to flesh coloured felspar, when there is a superficial

family resemblance to syenite. These changes are progressive and become rather marked in the uppermost few hundred feet near the roof, e. g. Tautesberg and Stoffberg north of Middelburg. Corresponding modifications are clearly seen in the chemical composition, which is distinctly more acid than that of the common norite of the Main Belt, e. g. that of the Pyramids north of Pretoria. Running parallel with these phenomena is a decreased specific gravity, and a change in the nature of the plagioclases, which now contain a higher proportion of the albite molecule.

N.B. As far as present knowledge goes, a chill phase at the roof, analogous to that traceable at the floor, has not been clearly established.

The preceding data are summarised in Table No. II; it should be recalled that the above five zones hold good primarily for the "lopolith" as seen in Eastern Sekukuniland; it does not necessarily follow that exactly similar belts are found all round the margin of the Complex. Some zones are probably either wanting or too feebly established to be clearly traceable, e. g. the Transitional Zone. In the Potgietersrust area it seems the two lowest zones are wanting, probably also the lower portion of the Critical Zone.

Table II. Petrographical Belts in the Norite „Lopolith", Eastern Transvaal.

Roof	Felsite and Quartzites of the Rooiberg Series				Intensely metamorphosed
	Petrographical Belts	Dominant Rock Types	Width	Rifting	
Norite „Lopolith"—Earlier Plutonic Phase of Bushveld Igneous Complex	5. Upper Zone	Bronzitite, with some diallage norite	Up to 2 miles (3,2 km)	Very feeble	Lighter Rocks; more leucocratic; less basic plagioclases
	4. Main Zone	Magnetite bands near top in contact with anorthosite; much common bronzitite	Up to 9 miles (14,5 km)	Weak	Much uniformity over great thicknesses
	3. Critical Zone	Bronzitite; diallage norite; pyroxenites; serpentines; dunites; chrome iron ore; anorthosite	Up to 3 miles (4,8 km)	Pronounced	Extreme differentiaton. Main Platinum horizons
	2. Transitional Zone	Bronzitite with occasional thin bands of pyroxenite. A little chrome iron	Up to 2 miles (3,2 km)	Very pronounced	Width very variable Sometimes not traceable
	1. Basal or Chill Zone	Fine-grained dark norite	Up to 100 yards (91,4 m)		Not always traceable
Floor	Shales and Quartzites of Pretoria Series				Intensely metamorphosed

f) General Characters of the Leading Rock Types.

The commonest variety which makes up the great bulk of the norite body, specially within the Main Belt is an evenly coarse grained rock, dark brownish or blackish on weathered surfaces, but mottled white and gray on a fresh fracture. As a rule it is massive, but not infrequently has a faintly banded structure due to the roughly parallel arrangement of the pyroxene. The mottled or spotted appearance is due to the association of white felspar and dark grey ferromagnesian elements; the former is commonly labradorite, while among the latter constituents bronzite is the most common, while hypersthene is rare. Hornblende is exceptional, though an essential element in certain pegmatites characteristic in some horizons belonging to the Critical Belt. Since bronzite is the dominant pyroxene, the most widespread type is not really norite or hypersthene-gabbro, but bronzitite; this variety shows a wide range in the relative proportions of salic and femic minerals and passes through many gradations into anorthosite and pyroxenite. More basic and darker coloured phases arise through the presence of chrome iron or diallage, accompanied by a marked reduction in the proportion of plagioclase. Here and there—notably in the Critical Level—one finds dark thoroughly basic types characterised by large individuals of diallage and conspicuous areas of poikilitic felspar—the latter sometimes covering several square inches; here belong the platinum bearing varieties with disseminated copper pyrites.

Pyroxenites are well marked in the lower belts of the Lopolith—sometimes forming prominent linear features displaying marked pseudostratification. They include dark greenish bronzite-bearing and almost black lustrous coarse-grained diallage-bearing varieties, with occasionally ilmenite as an accessory. The latter modification occurs at several horizons of the Critical Belt, both in the Lydenburg District and in the central or western portions of the "Lopolith".

Anorthosites, either free from ferromagnesian elements and thus practically pure felspar rocks, or with a slight admixture of pyroxene, occur as persistent bands —specially in the Critical Zone and in very intimate association with a sheet of magnetite near the top of the Main Belt—and are a prominent feature along the horizon of the platiniferous diallage norites forming the so-called Merensky Reef, e. g. more or less throughout the Lydenburg District, as well as west of Pretoria. In these anorthosites the felspar is thoroughly basic and belongs to the bytownite-anorthite end of the series[1]. A series of transitional phases connects the anorthosites through anorthositic norites, with the common mottled type described above. Certain phases show the pyroxenic elements aggregated into larger somewhat shadowy clusters; this is the so-called "spotted norite".

Rocks of the Peridotite family with olivine either still remaining or completely serpentinised include dark coloured to black very fine-grained serpentines (Mooihoek, De Kroon, Vlakfontein, etc.) and dunite. These are practically restricted to the Critical Belt. The true peridotites are almost black or—when fresh—dark olive green heavy coarse rocks very rich in hortonolite and of great economic importance through carrying minute particles of native platinum, locally in payable quantities. Unlike most of the other types, the dunites occur in cylindrical more or less vertical bodies, e. g. Onverwacht[2], of which a large number of separate occurrences are now known over many miles in the Lydenburg District.

Extreme ultrabasic differentiation has led to deposits of chrome iron and magnetite. The former usually occur in a series of parallel sheets up to two or three feet thick, and separated by anorthositic rocks. These deposits nearly always carry a small amount of interstitial felspar and are hence described as chromitite; they are an almost constant feature in the Critical Belt. The magnetite bands occur also as a group of bedded deposits likewise in contact with pure or spotted anorthosite, but occupy a distinctly higher horizon.

[1] WAGNER, P. A. "On Magmatic Nickel Deposits of the Bushveld Complex in the Rustenburg District, Transvaal. Memoir No. 21, Geol. Surv. Un. of S. Africa, Pret. 1924.

[2] WAGNER, P. A. and MELLOR, E. T. "On Platinum-Bearing Hortonolite Dunite of the Lydenburg District." Trans. Geol. Soc. S. Africa, Vol. XXVIII, 1925.

g) The Later Plutonic Phase

is the Red or Bushveld Granite, which occupies large continuous tracts hundreds of square miles in extent and forming the more central portions of the Complex. For the most part the form assumed by this granite is that of a gently inclined sheet emplaced between the felsites and quartzites of the Rooiberg Series on the plateau of Sekukuni's Mountain, in the Rooiberg area etc. Elsewhere it forms dyke-like or small stock-like bodies, detached from the main mass and sometimes intrusive into the norite lopolith. The thickness of the granite sheet is not known, since over much of it the roof has been denuded away, but it must have been at least several hundred yards thick; the source of its magma is to be sought in deepseated differentiation.

Unlike the norite lopolith, pseudostratification is nearly always wanting, but is locally sometimes traceable in the basal portions, e. g. near Zaaiplaats in the Potgietersrust area. As commonly developed, the granite is thoroughly massive and gives rise to large hummocky outcrops, familiar in many areas of granite.

The dyke-like occurrences surrounded by norite and forming apophyses from the main body are seen in several localities within the Steelpoort and Dwars River valleys in the Eastern Transvaal. The most conspicuous dyke of Red Granite lies some 2 miles (3.2 km) east of Magnet Heights in Western Sekukuniland and gives rise to a prominent ridge 4 miles (6.4 km) long and about $^3/_4$ of a mile (1.2 km) wide. Along its eastern and vertical contact with the norite there is a very coarse plutonic breccia composed in part of large angular blocks of norite, so that between the consolidation of the latter and the emplacement of the Red Granite phase, sufficient time must have elapsed to allow the norite magma to become thoroughly consolidated and rigid.

As typically developed, the Red Granite is an evenly coarse grained soda-rich rock, with a characteristic pale pink colour, when fresh, but becoming a more pronounced red, after prolonged exposure. It is made up in approximately equal proportions of felspar and quartz, with only a small proportion of ferromagnesian constituents. The felspar is essentially a microperthite made up of orthoclase and oligoclase-albite; the dominant femic element is biotite, but hornblende may also occur. Exceptionally one finds grey varieties (Albert Silver Mine) and others carrying payable quantities of cassiterite. (See under Economic Geology, page 194).

h) Metamorphism due to the Complex.

Both the floor and the roof are strongly metamorphosed all round the Complex, but the intensity of this alteration and consequently the thickness of the altered sediments varies within fairly wide limits, notably in case of the floor.

The surface width of the aureole and the depth to which the floor has been metamorphosed are shown in table No. III, which indicates that the influence of the Complex has been specially intense in its north-eastern (Malips Drift) and western portion (Zeerust):—

Table III. Variation in the Dimensions of the Aureole.

		Inner Belt. (approx. thickness)		Outer Belt. (approx. thickness)		Total Thickness (approx.)		Total Surface Width (approx.)
			m		m			
Central to Western Transvaal	Pretoria	1600 feet	480	—		1600 feet	450 m	$^3/_4$ miles (1.2 km)
	Hartebeestpoort	2500 ,,	760	—		2500 ,,	760 m	$1\frac{1}{2}$ miles (2.4 km)
	Hex River	3000 ,, 4000 ,,	914 1220	1000 feet	305	4000 ,, 5000 ,,	1220 m 1525 m	7 miles (11.2 km)
	Zeerust	6700 ,,	2030	3500 ,,	1060	10200 ,,	3110 m	16 miles (25.75 km)
Eastern to NE Transvaal	Belfast	2000 ,,	610	—		2000 ,,	610 m	$4\frac{1}{2}$ miles (7.2 km)
	Malips Drift	5200 ,,	1585	8000 ,,	2440	13200 ,,	4020 m	7 miles (11.2 km)

Since the intrusion of the Bushveld Granite occurred after that of the Norite "Lopolith", at a time when the latter had cooled sufficiently to have become thoroughly rigid, the later plutonic phase has no share in causing the intense alteration of the floor, an influence to be ascribed to the norite Lopolith alone. The remarkable variation in the thickness of sediments affected must be ascribed in part to differences in thickness of the intrusive body, and in part to exceptionally powerful pressure in certain sectors of the aureole, but is perhaps mainly due to an originally wider distribution of the lopolith notably along the major axis of the Complex.

The gradually increasing width of the aureole round the outer margin of the norite finally covers the whole of the Pretoria Series and even extends through the uppermost layers of the underlying Dolomite formation, e. g. south of Zeerust and in the Malips River valley; round Potgietersrust, owing to the powerful intrusive transgression referred to, the lopolith comes to lie successively against lower horizons of the Transvaal System, so that the entire thickness of the dolomite is strongly metamorphosed.

Usually the aureole shows an inner belt of highly altered completely recrystallised rocks (Hornfels Zone), followed by an outer belt of less altered rocks (Chiastolite Zone or Staurolite Zone); these belts shade into one another and cannot be sharply separated everywhere.

Except in the Potgietersrust area, the most frequent metamorphosed types are altered shales and quartzites of the Pretoria Series. In the outer belt the former are scarcely recrystallised, but show abundant and conspicuous contact minerals, notably chiastolite and andalusite, while their origin as shales and slates is still clearly seen (Longsight Type); in this belt the quartzites are hardly affected at all. Within the inner belt the argillaceous rocks are indurated, much darker in colour, and converted into many varieties of completely recrystallised hornfels ranging from compact to coarse phases, changes which show an orderly progressive intensity as one approaches the base of the lopolith; such rocks have lost much of their sedimentary characters in handspecimens (Groothoek Type). They have a highly characteristic glittering appearance due to countless flakes of metamorphic biotite; other common contact minerals are cordierite, garnet, sillimanite, and occasionally andalusite, but these are frequently not conspicuous in hand specimens. In the inner belt the quartzites are often—specially when pure—very coarsely recrystallised (Doornpoort Type). Where the Dolomite formation is affected, e. g. south of Zeerust and in the extreme north-eastern sector of the aureole, there is an abundant development of tremolite in conspicuous rosettes, and of actinolite, together with some scapolite.

Where the emplacement of the norite lopolith was accompanied by profound pressure (Malips Drift) the character of the metamorphic rocks is modified structurally and mineralogically. Thus from Belfast northwards a given horizon of only slightly altered shale passes gradually into the inner belt of more profound metamorphism and thorough recrystallisation, until within the Malips Drift area it finally passes into a coarsely crystalline dark Paragneiss[1] (Malips River Type). A similar progression converts normal quartzites into quartz-seritic-schists; in both types of altered sediments tourmaline is widely distributed. Mineralogically the modification is expressed through the Law of Volumes, e. g. garnet and staurolite are abundant and highly characteristic minerals, for the inner and outer belt respectively, throughout the Malips River area. In sharp contrast with these modifications, is the marked scarcity of Paragneisses in the inner belt, and the complete absence

[1] Hall, A. L. "Über die Kontaktmetamorphose an dem Transvaal System im östlichen und zentralen Transvaal. Wien, Tschermaks Mitt., 28, 1909, pp. 115—154.

of staurolite in the outer belt, of the aureole in the Zeerust area of the Western Transvaal, where tectonic results of the lopolith emplacement are quite subordinate.

From Potgietersrust northwards one finds a great variety of altered sediments, notably a wide range of coarsely crystalline lime-silicate hornfels, owing to the fact that the floor of the lopolith is brought into direct contact with dolomitic marl (belonging to the Pretoria Series) and with the Dolomite formation itself. Here occur very coarsely crystalline garnet-wollastonite-hornfels, rocks rich in zoisite, diopside, etc.

Intense metamorphism also affects foreign inclusions caught up by the norite magma; this applies e. g. to irregular masses of Magaliesberg quartzite found well away from the floor; these pass through intensely coarse recrystallisation into the Doornpoort type. Argillaceous inclusions are similarly converted into black crystalline hornfels of the Groothoek type, while carbonate rocks pass into pyroxene granulite, pink or grey garnet, and garnet-zoisite-hornstones, which develop a vivid green colouration when associated with chrome iron or bands (so-called "South African Jade").

Endomorphic modifications arise locally through the assimilation of sedimentary material. Where the latter was quartzitic, the resulting rocks, though still essentially igneous, become less basic and may show residual nests of undigested quartz (Hartebeestpoort Canal); where the foreign admixture was argillaceous, a type of hybrid or "contaminated" rocks is found, characterised by the combination of cordierite with ferromagnesian elements belonging to the norite group (Potgietersrust).—

The roof of the "Lopolith" has also been subjected to intense metamorphism, but since it is built up almost wholly of felsites and quartzites belonging to the Rooiberg Series, i. e. of rocks chemically not well adapted to the formation of contact minerals, the alteration is not striking mineralogically. The quartzites are very commonly metamorphosed into holo-crystalline rocks often pinkish through the presence of a fair amount of interstitial felspar, some of the latter possibly representing recrystallised original material, but probably there was also some transference of felspathic matter from the highest portion of the Upper Belt of the norite, which was shown above to be characterised by pink felspar (Western Sekukuniland).

This metamorphism leads locally to rocks having a very close resemblance to acid igneous rocks (Signal Hill near Magnet Heights). West of Warmbaths the roof of the Bushveld Granite is formed by quartzites, also of the Rooiberg Series; these are locally much altered and show the characteristic tourmaline rings due to pneumatolytic phases of the underlying intrusive granite. South of Pokwani the metamorphic influence of the norite lopolith on its roof probably accounts for a darkening of the felsites and their recrystallisation into somewhat coarser types.

The general nature of the metamorphism for both plutonic phases is essentially thermal, as shown by the mineral distribution and great abundance of the typical contact minerals:—biotite and cordierite, but in the northeastern section of the aureole, pressure was a powerful additional factor, as reflected in the development of Paragneisses in that area, together with special contact minerals:—garnet, staurolite, etc.

Table IV (p. 108) gives a summary of the more important features of the aureole.

i) Satellites ? of the Bushveld Complex.

Outside the limits of the Complex proper are several occurrences of intrusive igneous rocks which are possibly connected genetically with the main mass of the Complex, to some phases of which they bear a close general resemblance. On Dwarsfontein near Argent Station on the Springs-Witbank railway about 30 miles (48 km)

Table IV. Summary of Metamorphic Effects.

	Shales.		Quartzites.		Dolomites.	
	Inner Belt.	Outer Belt.	Inner Belt.	Outer Belt.	Inner Belt.	Outer Belt.
Aureole, excluding N.E. Transvaal. Metamorphic Rocks.	Hornfels of Groothoek Type.	Chiastolite Slate of Longsight Type.	Quartzites.	Quartzites.	Lime-Silicate Hornfels.	Altered Dolomite.
Structure.	Thickly bedded to almost massive.	Normally bedded.	Normally bedded.	Normally bedded.	Thickly bedded to massive.	Normally bedded.
Recrystallisation.	Complete	Feeble to Nil.	Complete and coarse in Doornpoort Type.	—	Complete and fairly coarse.	Nil to Feeble.
Contact Minerals.	Biotite, Cordierite, Andalusite, Sillimanite Garnet, Tourmaline.	Chiastolite, Andalusite.	—	—	Garnet, Wollastonite, Diopside, Zoisite etc.	Tremolite, Actinolite, Scapolite.
Nature of Metamorphism.	Essentially thermal throughout.					
Aureole in N.E. Transvaal. Metamorphic Rocks.	Paragneiss of Malips River Type.	Staurolite Slate abundant, some Chiastolite and Andalusite slates.	Quartzite Sericite Schist of Malips River Type.	Quartzites.	—	Altered Dolomite.
Structure.	Thickly bedded and gneissic in part.	Normally bedded.	Sheared in part.	Normally bedded.	—	Normally bedded.
Recrystallisation.	Complete.	Feeble to Nil.	Complete and coarse in Doornpoort Type.	—	—	Nil to Feeble.
Contact Minerals.	Biotite, Cordierite, Andalusite, Sillimanite, Crocidolite, Tourmaline; Garnet abundant.	Staurolite abundant.	Sericite, Tourmaline.	—	—	Actinolite, Scapolite.
Nature of Metamorphism.	Essentially thermal but with pressure metamorphism superposed.					

east of Johannesburg is a small mass of plutonic rocks, including red granite and gabbroid rocks and intrusive in the basal portion of the Pretoria Series; on Steenkopjes near Krugersdorp a small mass of pyroxenite cuts through and metamorphoses shales of the Timeball Hill horizon of the Pretoria Series; again in the Heidelberg Area are numerous masses of intermediate and basic rocks, intrusive in the Witwatersrand beds, and ranging from quartz-dolerite through pyroxenites to rocks composed chiefly of titaniferous magnetite; their strong resemblance to some of the rocks of the Bushveld Complex makes it very probable that they belong to that group.

In the Vredefort Mountain Land on both sides of the Vaal River some seven miles west of Parys are several small bosses of alkali granite or foyaite, intrusive into the Lower Witwatersrand System or into the Dolomite formation and certainly post-Pretoria Series in age. These little bosses are most likely portions of a much larger, and for the most part concealed, igneous body[1], which is intimately associated with nepheline syenite dykes. The latter probably belong to the same manifestation of intrusive activity to which belong several occurrences of alkali rocks, which may be regarded as a rejuvenated phase of the Bushveld Complex, notwithstanding the fact that this alkaline suite is distinctly later in age than the Red Granite and perhaps even of post-Waterberg date.

The most important group of igneous rocks and almost certainly a plutonic satellite of the main Complex forms the Great Dyke of Southern Rhodesia, built up of norites, peridotites, picrite, serpentines, etc. and traceable for over 300 miles (482 km).

Appendix to Bushveld Igneous Complex.

Nepheline Syenites and allied Alkaline Rocks in the Transvaal and Northern Orange Free State.

Distribution and General. A series of scattered intrusions of alkaline rocks, including various types of nepheline syenites, sometimes associated with alkaline volcanic phases, occur in the form of sheets, dykes and stock-like masses in the western, central and eastern Transvaal, as well as in the Vredefort Mountain Land both on the Orange Free State and Transvaal side of the Vaal River. Some of these masses are probably genetically related and belong to the same period of activity. The date of the latter is doubtful, but, notwithstanding the close geographical association of some of these alkaline masses with the Bushveld Igneous Complex, it is probable that they are of an age distinctly later than the main igneous events to which the granite and norite phases of that Complex belong, and that they represent the latest incident in its long magmatic history, which may have played into the Waterberg Period.

Main Occurrences. The principal areas of alkaline rocks may be grouped as follows:—The Pilandsberg in the Western Transvaal, the Franspoort Line east of Pretoria, Sekukuniland, the Vredefort Mountain Land, and the Heidelberg area. To the above must be added a series of occurrences in the form of dykes many miles long.

The Pilandsberg—the most extensive of these alkaline masses—is situated some 25 miles north-north-west of Rustenburg in the Western Transvaal, and is a circular group of hills, some 200 square miles (518 qkm) in extent and rising sharply out of the surrounding flat norite country. It is formed by an overlying series of alkaline lavas, with tuffs and coarse breccias, underlaid and invaded by nepheline syenites and felspar syenites arranged in concentric rings. Between the central plug,

[1] HALL, A. L. and MOLENGRAAFF, G. A. F. The Vredefort Mountain Land in the Southern Transvaal and the Northern Orange Free State.—Verh. Kon. Akad. Wet. II, Sect. XXIV, No. 3, 1925, Amsterdam.

which consists of syenite with altered nepheline, and the outer ring of felspathic syenite, there are four rings of syenitic rocks containing fresh nepheline. All of these are products of one magma, and all were intruded very nearly at the same time. It is not directly clear that central subsidence was the cause of the ring structure, but, wherever the dip of the tuff beds can be ascertained, it is directed inwards. Pilandsberg contains a larger mass of nepheline rocks than any other region that has yet been mapped in detail.

The intrusive phase is made up of light red to pink syenite, foyaite, lujaurite and other varieties of nepheline syenite; some of these contain sodalite, eukolite and astrophyllite, in addition to aegirine; fluorite is not uncommon. There are also dykes of the above types, basaltic dykes, and others of green fine-grained tinguaite. The volcanic rocks include breccias, tuffs, banded lavas, semivitreous and felsitic rocks, porphyrites and trachytic lavas[1].

The Franspoort Line[2] east of Pretoria covers several occurrences of alkali rocks on Franspoort, Leeuwfontein, Wolmansthal and Leeuwkraal, distributed along a line 23 miles (37 km) in length and running approximately north and south; it comprises four plugs and many dykes, all most probably derived from the same magmatic material, and consolidating both as intrusive and volcanic rocks.

The Franspoort body lies in a "poort" of the Magaliesberg quartzite range, covers about one-sixth of a square mile (half a qkm), and consists mainly of medium-grained light grey foyaite; with this are found dykes of monchiquite, camptonite, while the effusive phase is represented by soda-trachyte and phonolite.

The Leeuwfontein Complex[3] covers about two and a half square miles (6.4 qkm), and is surrounded by quartzites of the Pretoria Series; included in it are sodatrachytes, white syenite of the Aker Type (leeuwfonteinite), red syenite of the Umptek Type (hatherlite), nepheline syenites with inclusions of phonolite or of sodalite-bearing jacupirangite, and small dykes of bostonite, tinguaite, etc.

On Wolmansthal is a small plug of reddish foyaite intrusive in and surrounded by felsites of the Rooiberg Series.

The most northerly occurrence forms two bodies on Leeuwkraal, together covering about one square mile (2.6 qkm) surrounded by Karroo grits; one body consists of iron grey basaltic looking phonolite, while the other is even-grained foyaite, very much like that of Franspoort.

As in the Pilandsberg, so in the Franspoort fluorspar is occasionally found in the alkali rocks.

The alkali rocks of Sekukuniland[4] form a stock or plug some 7 square miles (18 qkm) in extent and intrusive in the felsites and granophyres of the Rooiberg Series. It shows much petrographical variation and comprises more or less schistose aegirine foyaite, microfoyaite and lujaurite, leucocratic and melanocratic facies of

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[1] "The Geology of the Pilandsberg"—Ann. Rep. Geol. Survey for 1911, p. 77, Pretoria, 1912; and "The Volcanic Rocks of the Pilandsberg"—Trans. Geol. Soc. S. A. 15, 1912, p. 100.

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[2] Shand, S. J., "The Alkaline Rocks of the Franspoort Line, Pretoria District"—Trans. Geol. Soc. S. A. 25, 1922, pp. 81—100.

[3] "The Igneous Complex of Leeuwfontein, Pretoria District", Trans. Geol. Soc. S. A. 24, 1921, pp. 232—249.

[4] Shand, S. J. "The Nepheline Rocks of Sekukuniland." Trans. Geol. Soc. S. A. 24, 1921, pp. 111—149.

coarse and fine-grained rocks, red ijolite, black ijolite, microijolite, urtite and other kinds. Some varieties carry wollastonite-pectolite, melanite-garnet and abundant apatite. Included in the alkaline stock is a mass of white crystalline limestone, covering about half a square mile (1.3 qkm) and not less than 300 feet (91 m) thick. It is characterised by crocidolite, apatite, opal and granular magnetite. According to SHAND, this limestone is a great block belonging to the Dolomite Series of the Transvaal System, brought up by the rising magma.

Within the Vredefort Mountain Land, alkali rocks are represented by a group of soda-granites and a series of nepheline syenite dykes[1].

The alkali granites form three small inliers, the largest about 2 square miles (5.1 qkm) in extent, two of which are intrusive in quartzites and shales of the Lower Witwatersrand System some 8 miles (12.9 km) west of Parys, while the third has cut through the Dolomite Series of the Transvaal System about 12 miles (19.4 km) north of Parys. The emplacement of these masses was accompanied by incorporation and assimilation of the surrounding strata and by contact metamorphism. These alkaline rocks are light-coloured, pale pink or greyish, medium to fine-grained somewhat acid arfvedsonite-soda-granites, with microcline and albite as the dominant felspars, and closely related to the soda-granites accompanying the nordmarkites of the Christiania region and to the arfvedsonite granites of Greenland.

The presence of these alkali granite inliers assumes great interest as they most likely are the visible portions of a more extensive body for the most part still concealed. To the latter must probably be attributed[2] the intense and widespread metamorphism of the Lower Witwatersrand rocks, traceable for many miles in the Vredefort Mountain Land. In places these results affect the entire thickness of the lower division of that System, the altered rocks occupying a surface width up to four miles. The principal metamorphic rocks are:—Cordierite-biotite-hornfels, andalusite-biotite-hornfels with or without garnet (Hospital Hill Slates), garnet-actinolite-hornfels (Water Tower Slates), etc. All these are holocrystalline, dark rocks locally very coarse, and frequently show the contact minerals to the naked eye. The basal amygdaloid has also been intensely altered and converted into hornblende-granulite. The alterations of these rocks may mean a case of polymetamorphism in two successive components. The earlier is regional and its essential agent static pressure; it gives rise to a narrow ring of hornblende-granulite and garnet-amphibole-hornfels round the central older granite, and is due to the load of superincumbent strata (Witwatersrand, Ventersdorp and Transvaal Systems). The later component is local, and its essential agent is heat (aided by pressure); its effects are distributed excentrically with reference to the central older granite and form an irregular area built up of many varieties of crystalline hornfels, e.g. andalusite-biotite-hornfels. Its cause is the emplacement of a large younger intrusion of alkali magma, which consolidated as the alkali granite referred to above. Superposition of the regional and local components occurred along the segment of the Vredefort Mountain Land stretching from about Leeuwdoorns west of Vredefort to near Brakfontein north-east of Parys, and tends to produce reinforced metamorphism shown by coarser recrystallisation and increased size and abundance of some of the metamorphic minerals.

The nepheline syenites form a series of dykes up to 50 feet (15 m) thick intimately connected with the soda-granite intrusions; they are found cutting the

[1] G. A. F. MOLENGRAAFF and A. L. HALL: "Alkali Granite and Nepheline Syenites, Canadite and Foyaite, in the Vredefort Mountain Land, South Africa." Proc. Kon. Akad. Wet. Amsterdam, 27, 1924, pp. 465—486.

[2] A. L. HALL and G. A. F. MOLENGRAAFF: "The Vredefort Mountain Land in the S.Transvaal and the N. Orange Free State". Verh. der. Kon. Akad. van Wet., Amsterdam, 1925.

latter or extending through the surrounding sediments in vertical masses. Those found in or close to the soda-granite west of Parys show extreme and rapid variation in grain and composition, but are all characterised by much albite as the ruling felspar, and thus fall into the Canadite group; a streaky or banded structure is occasionally well marked, and there are also excessively coarse pegmatitic phases. The soda-granite north of Parys is cut by a powerful dyke of pale pink foyaite up to 80 feet (24 m) wide aligned in a north-north-easterly direction, and traceable for at least 5 miles (8 km).

In the Heidelberg area[1] a few-pre-Karroo alkaline dykes following a nearly east-west course and belonging to the sölvsbergite, grorudite and quartz keratophyre groups; some of them are characterised by riebeckite and aegirine.

Other Alkaline Dykes. In the western Transvaal are a series of sub-parallel alkaline dykes, mostly made of elaeolite syenite, extending for many miles in a general northerly, north-north-easterly, or north-easterly direction; several of these cut through the Magaliesberg Range nothwards across the basic margin of the Bushveld Igneous Complex into the alkaline mass of the Pilandsberg; towards the south some of them closely approach the Vredefort Mountain Land; it is probable that a genetic connection exists between these dykes and the alkaline rock masses both of the Pilandsberg etc. and those found in the Vredefort Mountain Land. The most important examples are the Wonderfontein dyke at least 70 miles (112 km) long, and probably identical with the one found cutting the soda-granite north of Parys—and the Breedt's Nek dyke, a coarse greenish grey elaeolite syenite 35 feet (11 m) wide.

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[1] For details see A. W. Rogers: "The Geology of the Country round Heidelberg": An Explanation of the Geological Map. Pretoria, 1922, pp. 64—65.

The post-Nama Granites of the Cape Province.

By

A. W. ROGERS.

In the west and south of the Cape Province there are 17 separate occurrences of granitic rocks intrusive in the Nama or supposed Nama beds. In the two easternmost bodies, in George and Mossel Bay, the identification of the invaded sediments is open to doubt, and the development of large andalusite crystals in the contact schist there is exceptional.

The granites often have muscovite and biotite, though biotite preponderates. Parallel structures and banding are seen near the periphery of an individual intrusion, but are not general in the interior. Garnet, sillimanite and cordierite are rare constituents in the post-Nama granites of the Cape as compared with those of pre-Nama age. The granite near Cape Town has long been known for the abundance of altered cordierite in it, and that of Schapenberg in Somerset West has much andalusite in places. Orthoclase appears to be the predominant felspar in all these granites.

The granite intrusive in the Nama sandstones, slates and limestones of the Moed Verloren hills of Van Rhyns Dorp must have a boundary against the pre-Nama granite which forms the floor on which the basal Nama beds of Nieuwerust rest, but no satisfactory character is yet known by which individual outcrops of the two can be distinguished. The largest mass of the post-Nama granite is that which extends from St. Helena Bay for 70 miles (112 km) past Saldanha Bay, Darling and Mamre. Near Kapor Berg there are many inclusions of dark granulite rocks of which the origin is obscure. Quartz porphyry is abundant on the eastern side of this mass. This is probably a composite mass, on a larger scale than that of Schapenberg described by Mr. WALKER. It and the other large masses of Paarde Berg, the Paarl, Wellington and Stellenbosch are elongated parallel to the strike of the invaded Malmesbury beds. The granite of the prominent mountain near Robertson is peculiar in its apparent independence of structural lines in the surrounding sediments and the very slight changes brought about in their mineral composition.

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6. The Waterberg-Matsap System.

By

A. L. HALL.

a) Distribution and General.

This is a non-fossiliferous and predominantly an arenaceous system, in which reddish or purplish quartzites or quartzitic sandstones are the principal lithological element. Conglomerates, often rather coarse, are frequently found, while shales also occur occasionally. There are two main developments of these rocks. The first lies in the central and northern Transvaal and constitutes the Waterberg System proper; the second occurs in the Cape Province and forms the Matsap Series, being correlated with the former on account of its stratigraphical position and lithological characters. These two areas are geographically distinct and have not yet been proved by mapping to be connected. (Fig. 28).

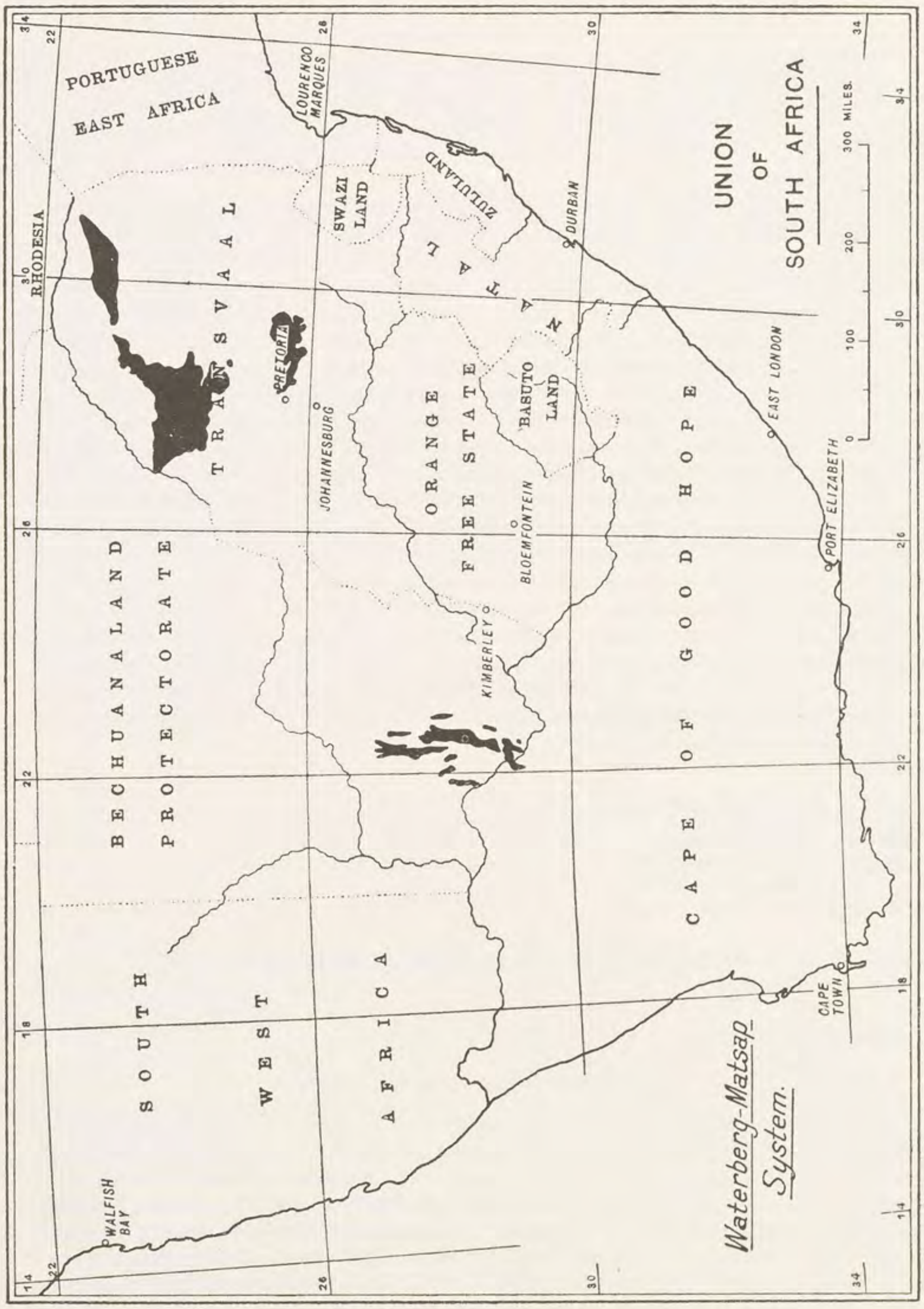

Fig. 28. Outline Map showing the distribution of the Waterberg-Matsap System.

In the Central Transvaal the Waterberg System occupies an extensive tract of country belonging to the Pretoria and Middelburg Districts and situated north of the Delagoa Bay railway, extending for some 40 miles (64 km), from the Elands River to near Middelburg, with a maximum width of about 15 miles (24 km). This distribution corresponds to roughly 600 square miles (1550 qkm) of country, but here and there the continuity is broken by small irregular patches of horizontally bedded Dwyka Conglomerate and Coal Measure grits belonging to the Karroo System, which lie unconformably on the Waterberg rocks.

In the northern Transvaal Waterberg rocks cover an enormous tract of country in the Waterberg, Potgietersrust and Zoutpansberg districts, amounting approximately to over 7000 square miles (18130 qkm) and extending well over 100 miles (160 km) from Warmbaths across the Zwagershoek Mountains over the whole of the Palala Plateau to the Blaauwberg, whence the system continues eastwards along the Zoutpansberg Range, which defines the northern limit of the Older Granite of the Pietersburg district.

The rocks grouped as the Matsap Series[1] (named after the locality Matsap in the division of Hay) are found in the northern parts of the Cape Province:—Bechuanaland, Griqualand West, Prieska, and in the south-eastern corner of the Kalahari. The formation gives rise to a conspicuous range of mountains, the Ezel Rand, Langebergen and Korannabergen. Unlike the Waterberg System, the Matsap Series forms a large number of separate outcrops in long narrow strips of country trending from south to north.

The thickness of the Waterberg System in the Middelburg district is 5000 feet (1525 m) approximately; west of Zaaiplaats on the Palala Plateau it is about 4500 feet (1372 m), but north of Doornhoek it is estimated at from 8000 to 9000 feet (2438 to 2743 m). The thickness of the Matsap Series is over 7000 feet (2134 m).

Prior to 1922 the Waterberg System embraced—under the name Lower Waterberg System—a group of felsitic lavas (with thin intercalations of shales) known as the Volcanic Series, and an overlying Shale and Sandstone Series. During 1922 the Shaler Memorial Expedition under Professor R. A. Daly[2] in conjunction with the Geological Survey re-examined the supposed intrusive contacts at Balmoral east of Pretoria and at Gatkop west of Warmbaths; the "Upper" Waterberg beds were found to lie with a sedimentary contact on the granite. The term Waterberg System is now restricted to what was formerly classed as "Upper" Waterberg, the so-called "Lower" Waterberg (made up of the Shale-Sandstone and the Volcanic Series) being assigned to the Rooiberg Series as the uppermost group of the Transvaal System. This change is shown in the following table:—

Classifications of the Waterberg System in the Transvaal.

	Stratigraphy prior to 1922.	Present Stratigraphy.
Waterberg System	Upper Division a) Sandstone and Quartzite Series:—Sandstones, quartzites, grits and conglomerates.	Waterberg System.
		Unconformity
	Lower Division a) Shale and Sandstone Series:—Shales, soft sandstones and conglomerates. b) Volcanic Series:—Lavas, tuffs, breccias, and agglomerates with interbedded shales and sandstones.	Rooiberg Series (= Uppermost division of the Transvaal Syst.)

[1] The earliest description is due to Stow (Quart. Jl. Geol. Soc. London, Vol. 30, 1874); the term "Langeberg Schichten" is used for this series by Passarge "Die Kalahari", Berlin 1904, p. 69.

[2] R. A. Daly and G. A. F. Molengraaff: "Structural Relations of the Bushveld Igneous Complex, Transvaal." Journal of Geology, Vol. 32, 1924, p. 1.

b) Field Relationships and Local Characters.

1. East of Pretoria, in the Pretoria and Middelburg districts **the Waterberg system** rests unconformably on the Pretoria Series, sometimes on the shales and quartzites, elsewhere on the volcanic rocks of the Rooiberg Series, forming a great succession of thickly bedded quartzitic sandstones and well defined conglomerates. The unconformity is well seen on the left bank of the Wilge River or close to Balmoral Station. At the former locality the sandstones and conglomerates are inclined at 10^0 in a direction north 27^0 east, and rest on an eroded surface of Pretoria beds, inclined 2^0 in a direction south 67^0 west. At Balmoral the horizontal sandstones lie on Pretoria quartzites which dip from 20^0 to 25^0 in a direction north 24^0 east. In both exposures the base of theWaterberg System is a breccia composed of hard white quartzite fragments in a brown sandy matrix, these fragments having been derived from the Pretoria quartzites supporting the breccia. As pointed out above, the system is now and then overlain unconformably by irregular outliers of Karroo rocks.

Usually the Waterberg System is inclined at low angles of 5^0 to 12^0. North and north-west of Middelburg it has been thrown into huge synclinal fold, much of which forms a high plateau flanked on several sides by conspicuous escarpments of sandstone, encircled by depressions due to softer underlying shales of the Rooiberg Series. This syncline is not perfectly symmetrical, since the average dip along the northern limb is considerably greater than that along the southern edge. Extremely disturbed conditions prevail near the junction of the Wilge and Olifants Rivers, where the beds become vertical. Such movements were accompanied by extensive faulting and folding and are well displayed along the northern limb of the syncline north-west of Middelburg, as well as further west in the overthrusts and inverted folds of the Rhenosterkop area. Probably a more sustained period of sedimentation combined with the presence of a synclinal structure favourable to more effective protection from denudation account for the exceptional thickness of this system north-west of Middelburg, in comparison with its development nearer Pretoria.

The Waterberg sediments throughout possess a very distinctive brownish red colouration, not unlike that of the Old Red Sandstone formation in Great Britain. This colour passes frequently into deep chocolate brown, purple and plum coloured tints. Long exposure gives rise to light green shades sometimes found mottling the deeper ground colour in spots or patches. After prolonged weathering some varieties of softer sandstone change in colour to pure white, so as to resemble coal measure sandstones.

Conglomerates are a conspicuous feature, notably at the base of the system, on the northern side of the Waterberg syncline, where they reach the phenomenal thickness of over 300 feet (90 m). These bands are thickly bedded, or occasionally almost without distinctive bedding planes, and often very coarse, fragments up to 8 feet (2.44 m) in diameter being sometimes found. The coarse and variable character of the conglomerate bands is well displayed between the Elands River and Bronkhorst Spruit. The pebbles and boulders consist largely of quartzite, shale and dolerite derived from the Pretoria Series, but fragments of older conglomerate, banded ferruginous slate, jasper, and felsite also occur, the last named from the underlying Rooiberg Series. In the upper portions of the System, there are several more regular, thinner, and more persistent conglomerate bands, showing well rounded pebbles rarely exceeding a few inches in diameter. The arenaceous beds in between these conglomerates may show scattered pebbles or short pebbly washes.

The bulk of the system is built up of a great sucession of fine-grained to coarse, thickly bedded sandstones and grits. These are rather soft, but pass through quartzitic sandstones into more durable quartzites; they are often strongly false bedded and show distinct ripple marks. Since they weather comparatively readily and are often associated with low dips over much of the central Waterberg plateau, they are often carved into fantastic table-like forms, splitting up into laminae disposed in all directions on account of current bedding.

Shales are quite subordinate, though locally attaining a thickness of 30 feet (9.1 m). They are soft chocolate or liver coloured rocks, disintegrating into minute fragments, and found chiefly in the lowest beds of the system.

MELLOR[1] has pointed out that the coarse breccias and conglomerates at the base indicate torrential origin and deposition close to the shore line of the Waterberg sea. The character of the sediments as a whole points to strong and variable currents, as shown by the extensive development of false bedding, while the giant conglomerates and breccias suggest flood deposits.

2. In the Northern Transvaal from Warmbaths northwards across the Waterberg and Potgietersrust districts, the bulk of the Waterberg System falls within the Palala Plateau, formed of massive, nearly horizontal sandstones, grits and conglomerates, having a slight centrally directed dip of 5° or less; the highest portion of this plateau rises about 5900 feet (1800 m) above sea level. Its edges are often marked by imposing escarpments carrying coarse conglomerates at their base and resting unconformably on the more steeply inclined shales and felsites of the Rooiberg Series; in the neighbourhood of Zaaiplaats the difference in dip amounts to 10°, while the basal conglomerate cuts across the outcrop of Rooiberg shales. Still further north the Waterberg beds come to rest directly upon the Red Granite of the Bushveld Complex. Where the massive and coarse basal conglomerate, which only show very indefinite beds, rests upon Rooiberg felsites having no bedding planes, the unconformity can often not be demonstrated.

Compared with the relatively simple structure of the Palala Plateau proper, the Waterberg System has been much disturbed further south, notably along the Hoekbergen north-west of Warmbaths. In consequence of intense pressure from the south the basal strata of Waterberg beds together with their supporting floor were tilted and overtilted, the area of maximum disturbance coinciding with Gatkop, a prominent peak capped by banded magnetite quartzites of the Transvaal System. These were thrust over the underlying Waterberg sandstones and over the Bushveld granite, subjecting the beds below the thrust plane to much shearing. These orogenic disturbances may be taken as post-Waterberg and pre-Karroo age.

In their lithological characters, the Waterberg rocks in this part of the Transvaal are very similar to those of the Middelburg District. Conglomerates are very persistent at or close above the base of the System, varying in composition and thickness. The latter frequently exceeds 100 feet (30.5 m) and may attain 200 or 300 feet (61 or 91.5 m), including a few insignificant bands of sandstone; elsewhere the thickness may drop to 6 feet (1.8 m), or very rarely the conglomerate may be wanting altogether; thus on Appingadam purplish-red false-bedded sandstones rest directly upon the Rooiberg Series. These conglomerates are normally coarse and thikcly bedded. Pebbles are plentiful in a dark purplish coarse sandy matrix, which may increase until the conglomerate passes into a coarse pebbly sandstone. Boulders a foot or more in diameter are frequent, though dimensions from one to six inches normally predominate. The fragments include red or purple felsites, variously coloured quartzites, magnetite jasper rocks, granite and tourmalinised rocks. In the Gatkop section the pebbles are frequently felsites, together with those of granite porphyry found in the immediate vicinity.

Above these conglomerates follows a great succession of sandstones and grits of the usual Waterberg type in brown and red colours, sometimes distinctly purplish;

[1] Annual Report Geol. Survey Transvaal for 1903, p. 17.

these are usually coarse and thickly bedded. The grits form a large proportion of the succession and often very massive. Numerous scattered pebbles, pebbly washes and irregular bands of conglomerates occur both in the grits and the sandstones.

Thinly bedded flaggy or shaly sandstones as well as shales also occur; thus on Rietfontein No. 1638 the basal conglomerates are succeeded by about 500 feet (152 m) of hard reddish purple flaggy shales.

Igneous rocks of basic character are occasionally found both in the Middelburg and Waterberg Districts as sheets and dykes intrusive in the quartzites of the Waterberg System. Here belong several occurrences north of Middelburg, round Nylstroom, also north of the Hoekbergen and west of Potgietersrust. For the most part these are moderately coarse greenish grey to dark green doleritic rocks, composed mainly of plagioclase and augite, together with some iron ores, and are more often intrusive sheets following the bedding planes of the sediments, than dykes. Exceptionally such sheets show an extreme degree of differentiation ranging from a thoroughly acid dark grey coarse dolerite to bright red granophyre (Rooiwal west of Potgietersrust).

These basic intrusions show considerable resemblance in the different localities and probably belong to the same period of intrusion, which is most likely of pre-Karroo age, since they differ markedly from those characteristic of the Karroo System. They are also certainly of later age than the Red Granite phase of the Bushveld Complex, of which they possibly represent a very late incident.

3. In the Zoutpansberg District of the Northern Transvaal the System gives rise to the prominent east and west trending range, from which the district takes its name. This range is made up of quartzites, sandstones and conglomerates of the same characteristic red or purple colouration, though detailed information on this area is not yet available.

The prevalent dip is from 12⁰ to 20⁰ to the north, but the succession has been affected by extensive faulting arranged somewhat obliquely to the strike, so that the beds form several parallel ridges with well marked escarpments facing southwards, as at Louis Trichardt. Probably owing to repetition by faulting, a belt of country some 12 miles from this village northwards, is occupied by these rocks. A zone of much crushed and brecciated rock may mark the lines of faulting.

The lithology of the system, as developed in the Zoutpansberg Range, on the whole closely resembles that exhibited by the Waterberg System further south, but conglomerates appear to be much less common. On the south side, however, a considerable thickness of basic amygdaloidal basalts and other volcanic rocks intervenes between the base of the System and their granitic floor. Their character and relationships have not yet been studied, but they may be regarded as indicating a period of contemporaneous volcanic activity associated with the Waterberg System. Possibly they are analogous to the volcanic beds found in the Matsap Series, though these occur in the middle division of that group.

Igneous rocks are well represented in the Waterberg System, both in the Middelburg area and west of Warmbaths and of Potgietersrust. Here belong dolerite, gabbros and other basic types in the form of numerous sheets, and less commonly of dykes. In the former case differentiation locally resulted in felsitic and granophyric phases. Dykes of felsite-porphyry are also found, cutting the sandstones e. g. in the Palala Plateau[1] at the foot of Platkop.

4. The **Matsap Series** of the Cape Province lies unconformably on beds belonging to the Ventersdorp and Transvaal Systems, and is unconformably covered by the Dwyka Series. The correlation with the Waterberg System of the Transvaal

[1] G. A. F. Molengraaff, Annual Report State Geologist for 1898, Pretoria, 1902, p. 22.

is based on the very close resemblance in lithological characters, both being essentially arenaceous groups, and on the position of the Series intermediate in age between the Griqua Town (Pretoria) Series and the Dwyka.

The series forms a great thickness of purplish quartzites with conglomerates and shales; the dominant character of the group is arenaceous. The beds usually lie at high angles with a prevalent dip to the west, while large folds, in places nearly isoclinal and with their axial planes inclined eastwards are well marked in the upper division. Fig. 29 gives a general idea of the relationship between this series and the Griqua Town Series of the Transvaal System[1].

The Matsap Series is divided into three groups, but the middle group is sometimes concealed or absent:—

Upper Beds:—chiefly quartzites, grits and sandstones. Several thousand feet thick.

Middle Beds = Hartley Hill group:—characterised by volcanic rocks. 4000 feet (1220 m) thick.

Lower Beds:—quartzites, shales and conglomerates. 3000 feet (915 m) thick.

The Hartley Hill group has only been found on the east side of the Langebergen.

The Lower Beds include conglomerates and shale bands in addition to quartzites and grits. The basal conglomerate in the Gamagara ridge is crowded with fragments of Griqua Town Beds, though at the south end of the Matsap ridge the series rest unconformably upon Griqua Town beds, with no marked conglomerate. Some of the conglomerates have a hard quartzitic matrix with pebbles of quartz, quartzite, jasper, diabase, and granite. Elsewhere the matrix becomes red and ferruginous, the beds being sometimes much sheared, and the boulders or pebbles stretched and flattened. The shales are slaty rocks with much sericite and found chiefly in the eastern and western foothills of the Langebergen.

The rather coarse quartzites, sandy phyllites and grits of these Lower Beds are purplish or reddish-grey rocks, with a bluish colour on surfaces recently exposed, with their grains well rounded. Scattered well rounded pebbles of

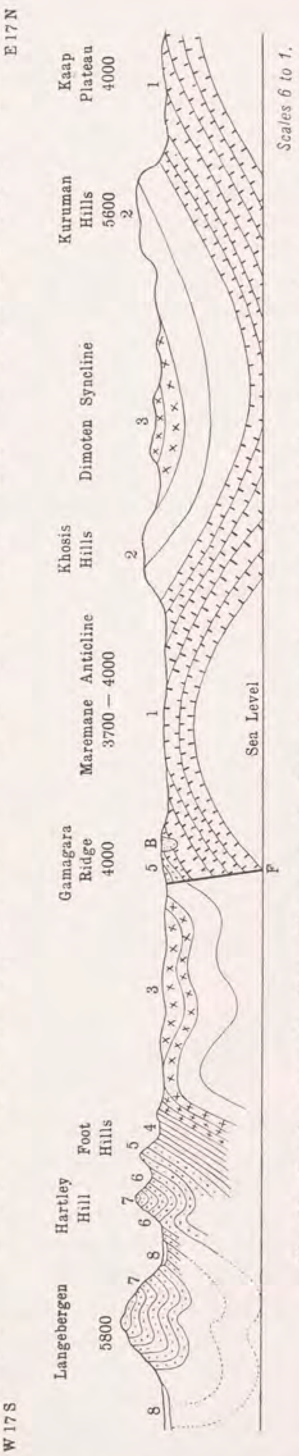

Fig. 29. Section from the Kaap Plateau to the Langebergen, Kuruman District, Northern Cape Province.
1. Campbell Rand Series. 2. Lower Griqua Town Beds. 3. Middle Griqua Town or Ongeluk Beds. 4. Upper Griqua Town Beds. 5. Lower Matsap Beds. 6. Middle Matsap Beds. 7. Upper Matsap Beds. 8. Surface Sand, etc.
B. Blink Klipp Breccia. F. Paling Fault. Distance 66 miles (106 km).

[1] Recent work by Dr. L. T. NEL (to be pubished as a Geological Survey Memoir on the Postmasburg area) indicates that the fault west of the Gamagara Ridge is a thrust plane.

quartz, quartzite or red jasper occur in all quarzite horizons. Collectively these quartzites are very similar to those which make up much of the middle and the whole of the upper divisions. They are distinct from other rocks in the Cape Province and their boulders have been definitely recognised in the Dwyka Conglomerate.

In the Middle Beds occurs a considerable thickness of lavas, breccias and tuffs. At the base is a conglomerate with a dark green matrix like that of the overlying volcanic breccias. The lavas are much altered, often amygdaloidal, and probably belonging to the hornblende-andesite type, but containing much green secondary material, together with cherty silica and calcite. Some of the conglomerates carry rounded boulders of lava together with rocks older than the Matsap Series, indicating local unconformities and subaerial waste of the lavas. Normal quartzites and grits of the Matsap types are well developed, but include white and green varieties.

The Upper Matsap Beds form the greater part of the Korannabergen and consist almost entirely of purplish quartzites and grits with some seritic rocks, but no slates or conglomerates.

In the south-eastern corner of the Kalahari the Matsap Series gives rise to several ranges, including the Inkruip, Karreeboom Laagte Hills, the Kamkuip and others; some of these are on the strike of the Karannaberg, but a wide stretch of sand hides the rocks for great distances. In these localities the rocks are like those of the Lower and Upper Matsap groups, but cleavage is more marked, since the rocks contain material favourable to the formation of sericite and have been subjected to great pressure during crustal movements. North of the Kalahari Mountains on the Molopo Rover steeply dipping purple quartzites crop out in the valley; these must also belong to the Matsap Series. They are unconformably overlain by the Dwyka Series.

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7. The Cape System.

By

S. H. Haughton.

The rocks belonging to the Cape System are found in the south and west of the Cape Province, and in the south-east of the Union in Pondoland and Natal (see Fig. 30). The fullest development is in the former area, where there is a complete succession passing conformably upwards into the Karroo formation. In Pondoland and Natal only the lowest series is found.

The system is divided into the following series:—

3. Witteberg Series (sandstones, quartzites and shales).
2. Bokkeveld Series (shales and sandstones).
1. Table Mountain Series (sandstones, quartzites and subsidiary shales).

In the south and west of the Union the rocks comprising the System are highly folded and build up the series of mountain ranges and intermontane longitudinal valleys that form the "Cape Folded Belt" in the south and south-west and the Cedarbergen further to the north.

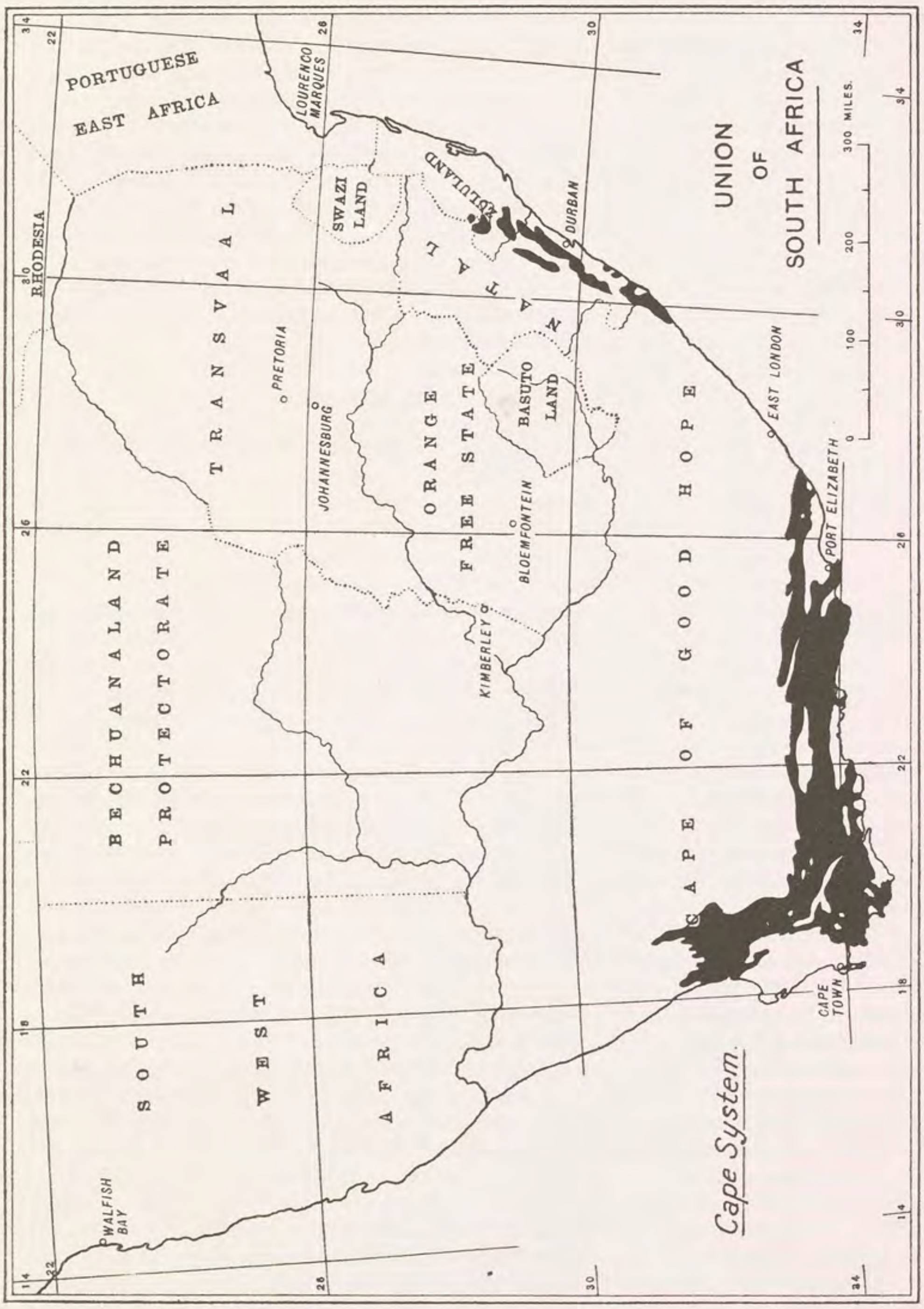

Fig. 30. Outline Map showing the distribution of the Cape System.

The removal of the Cape formation by denudation in pre-Karroo times north of lat. 33⁰ is demonstrated in the western Karroo. The place where the unconformity at the base of the Karroo System commences is not known precisely, but it lies near lat. 33⁰, north of which the Lower Dwyka Shales have not been recorded. The Dwyka Tillite rests on lower and lower horizons of the Cape System as it is followed northwards, and it lies on the Table Mountain Series at the Oorlogs Kloof River. The Table Mountain Series is last seen as a thin white sandstone forming a cliff 10 feet high at the north end of the Bokkeveld Mountain, while to the east, in the Doorn River valley, it disappears as a thin wedge between the Nama beds below and the Dwyka Tillite above. In Pondoland and Natal the Table Mountain Series lies almost horizontally, and is unconformably overlain by the Dwyka Tillite. Where the Cape System is cut through slantwise by the coast south-west of the Keiskama River it is overlain conformably by the Lower Dwyka Shales and its full thickness is developed. The region in the east corresponding to that where the unconformable overlap takes place in the west lies under the sea.

1. Table Mountain Series.

This group of rocks dominates the scenery of the south-west and south as far east as Port Elizabeth. It can be divided into:—

4. Upper Sandstone
3. Upper Shales
2. Main Sandstone
1. Basal Shales.

It has a maximum thickness of about 5000 ft. (1520 m), and of this more than 4000 ft. (1220 m) consists of sandstones and quartzites often false-bedded.

The Basal Shales are not constantly developed; but where they occur, as in the Cape Peninsula and neighbouring areas, they consist of thin-bedded red micaceous gritty or sandy shales, very false-bedded resting on a peneplaned surface of older rocks. The actual basal bed may be an arkose or, as in parts of the Langebergen, a band of quartzites. In several places in Pondoland brick-red or maroon coloured soft micaceous shales are developed at the base of the series; the very basal layer may contain granite debris where it rests upon a surface of that rock. These basal shales are the only part of the series which has so far yielded fossil remains—a few indeterminate casts of lamellibranchs having been found in the beds on Table Mountain.

The main sandstone band consists of well-jointed, often false-bedded, sandstones with thin and impersistent lenticles of shale along the parting planes. As they are traced eastwards the sandstones become quartzitic and very well-jointed. The sandstone in a fresh condition is bluish-grey in colour; but it weathers to a whitish-grey or to a reddish-brown rock. The rock is even-grained; but a characteristic feature is the occurrence of rounded pebbles of white quartz or quartzite up to an inch or two in length, which are sometimes confined to definite horizons and rarely collect to form conglomerate layers, but are rather more often sparsely scattered through the rock. On the west coast conglomerate is seen more often than elsewhere.

In Pondoland this main sandstone, with the basal shales, attains a maximum thickness of 2000 ft. (600 m), whilst in Natal denudation has proceeded to such an extent that the formation rarely exceeds 600 ft. (183 m) in thickness. Here the sandstones are often gritty in grain and felspathic, sometimes becoming arkoses, especially near the base. These felspathic bands are frequently red or even purplish in colour; but higher zones are of the normal withish variety of sandstone. The red felspathic varieties must be considered as merely a local phase of the white siliceous sandstones.

About 1000 feet (305 m) from the top of the Series in the south and west of the Cape Province there is a second shale band (the "Upper Shales") from 150 feet (45.7 m) to 300 feet (91 m) thick which, on account of its easy weathering, forms a prominent band of gradual slope in the mountain regions . At the base of this there is a glacial tillite—consisting of greenish blue or reddish mudstone containing scattered pebbles and boulders which are of varying size and which often show flattened and striated surfaces. The boulders are made of quartz, quartzites, sandstones, red jasper, chert, amygdaloidal diabase and granite. The tillite is widespread, having been traced at various points from the Cedarbergen in the north southwards to Table Mountain and thence eastwards to the Zwarteberg Pass. Its maximum thickness is 100 feet, but it thins eastwards—in which direction the included pebbles become fewer and smaller.

Below the tillite, in the mountains stretching from Somerset West to the Hex River Range, the sandstone below the glacial band has been thrown into a series of synclines and anticlines (infraglacial folds) to a depth of 200 feet (61 m) or so. The anticlines are often overfolded, and their tops are occasionally truncated and overlain by a persistent unfolded band of tillite. Tillite, too, fills many of the centres of the synclinal folds; and it is evident that the folding was subglacial, and due to the passage of an ice-sheet in a direction from west to east over a partially consolidated sandstone. The shales above the tillite are either soft, greenish banded clays, or, as at French Hoek, black slates with pebbles; and they may be looked upon a fluvio-glacial deposits of the nature of varve-clays.

Lithologically, the upper sandstone resembles closely the main sandstone.

The rocks of the Table Mountain Series form most of the mountain ranges in the west and south. The chief folded ranges of the south, the Zwarteberg, Langeberg Outeniquas, Zitzikamma, and Kouga Mountains strike nearly east and west; in the west, the axes of the ranges from the north end of the Cedarbergen to Cape Hangklip run a little west of north. Between Ceres and Bredasdorp there is an intermingling of these two sets of folds and the consequent production of a diagonal set with a north-easterly course and a less important diagonal set striking north-west. In nearly every case the mountain range is formed by an anticlinal fold; but numerous minor intense folds occur within each range. The folding is most intense in the east and west trending chains; northwards from Tulbagh the arches are less sharp and less numerous. The anticlines of the Cedarberg flatten out northwards.

In Pondoland and Natal, the beds of the Series are either horizontal or have a very low dip. They are affected by both pre-Karroo and post-Karroo faulting, and at Port St. Johns the sandstone stands up as a horst surrounded by Karroo beds. The Series thus naturally gives rise to table-topped scenery, and there are no continuous mountain ranges formed by it.

The series as a whole yields a poor, sandy soil which becomes black through an admixture of organic matter in places which are continuously damp. Forming as it does large elevated regions in an area of good rainfall and composed in the main of well-jointed permeable rocks, the series contains a large water-supply, which partly issues in numerous springs near the base. Wherever it has been tapped by boring, good supplies of water have been obtained; and the water is very free from deleterious mineral salts.

2. Bokkeveld Series.

This series is developed only in the south and west of the Cape Province, and it lies conformably on the Table Mountain Series. Where typically developed the beds consist of shales and sandstones arranged in a definite order, although the details vary from one locality to another. The maximum thickness is about 2500 ft. (762 m), but in the north the series becomes thinner, the uppermost beds having been removed by denudation before the deposition of the base of the Karroo System. The series as a whole forms the lower lying ground of the major synclinal valleys in the Folded Belt, along which run the longitudinal streams; but the beds give rise to a diversified type of country on account of the varying degrees of resistance to the agents of denudation offered by the harder sandstones and softer shales. In the north of the outcrop, where the beds are flatter, the scenery is less diversified; and south of the Langeberg Tertiary peneplanation has cut the beds down to a nearly level plain, which is, however, deeply dissected.

The lowest division consists of shales and thin sandstones about 300 feet (91 m) thick, containing many marine fossils—trilobites, brachiopods, lamellibranchs and crinoids. Spherical or elliptical nodules filled partly with red or yellow ochre are fairly common in the shales; whilst some of the shales are coloured black by the amount of carbonaceous matter in them.

Above this subdivision comes the first or fossiliferous sandstone, which is a dark blue rock weathering deep red outside. The sandstone, which contains thin bands of blue shale, is about 150 feet (46 m) thick. In places it is highly fossiliferous, various species of *Spirifer* and *Leptocoelia flabellites* being the commonest forms.

The second group of shales, above the first sandstone, is also fossiliferous, and varies in thickness from 100 to 300 feet (30.5—91 m). Above it is the second sandstone, 400 feet (122 m) thick, which weathers into light-coloured outcrops, contains few fossils, and has many intercalated shale-bands.

The third group of shales is about 350 ft. (107 m) thick, has some bands of thin quartzites, and contains a few marine fossils. Above this occurs a series of sandstones and shales, which are often very micaceous, and which have not been proved to contain invertebrate remains. They contain, however, plant fossils—*Lepidodendron* and others—which are closely allied to those of the succeeding Witteberg Series; and a further point of resemblance is the occurrence of *Spirophyton*. The Bokkeveld Series is thus divisible palaeontologically into a Lower and an Upper Division, of which the former contains marine invertebrates, and the upper no fossils other than plant-remains.

The fauna of the lower division is an interesting one. COWPER REED has recently listed 186 forms, among which the following are the more important forms:—(Echinoderms) *Placocystis africanus*, *Codaster* aff. *pyramidatus*, *Ophiocrinus stangeri;* (Brachiopoda) *Lingula Keideli*, *lepta*, *scalprum*, *Orbiculoidea* cf. *collis*, *baini*, *Orthis satelles*, *Stropheodonta arcei*, *concinna*, *Schuchertella sulivani*, *Chonetes falklandicus*, *stübeli*, *Spirifer antarcticus*, *ceres*, *Cryptonella baini*, *Leptocoelia flabellites*, *Ambocoelia pseudo-umbonata*, *Rensselaeria montaguensis*, *Scaphiocoelia africana*, *Derbyina* spp., (Lamellibranchiata) *Nuculites* spp., *Palaeoneilo* spp., *Nuculana inornata*, *Modiomorpha* spp., *Janeia baini*, *braziliensis*, *Grammysia* spp., (Pteropoda) *Conularia africana*, *baini*, *ulrichana*, *quichua;* (Gasteropoda) *Platyceras*, *Loxonema* spp., *Bellerophon* spp.; *Orthoceras* spp.; (Trilobites) *Proetus malacus*, *Cyphaspis dereimsi*, *Dalmanites* spp., *Phacops* spp., *Typhloniscus baini*, *Homalonotus* spp., *Acidaspis* spp.

This fauna shows many points of similarity with that of the Devonian rocks of various parts of South America and of the Falkland Isles; while the differences between it and the corresponding boreal faunas of North America and Europe are strongly marked. The fauna as a whole leads to the conclusion that the Bokkeveld Beds are rather of Lower Devonian than Middle Devonian age. Although the lithological subdivision of the series is obvious, it has not yet been found possible to group the beds into zones on the basis of the contained fossils. The upper half of the series must be considered, on palaeontological grounds, as forming part of the succeeding Witteberg Series.

South of the Langebergen the Bokkeveld beds are distinctly finer-grained than to the north; and the shore-line of the sea in which they were deposited must have crossed South Africa in a general east-west direction to the north of the area now occupied by them. This sea must have been continuous with that in which the Devonian beds of South America were deposited, washing the shores of the continent to the north which has been called Falklandia by J. M. CLARKE.

The country occupied by the Bokkeveld Beds is, in general, much more fertile than that formed by the Table Mountain Series; the shales in particular form rich soil, which is used for agricultural and garden purposes. Water issues in the form of numerous springs along the junction of the Table Mountain Sandstone and Bokkeveld Shales; and good supplies are sometimes obtained by boring. Much of the water is, however, rather highly charged with mineral salts, or with sulphuretted hydrogen due to the mutual decomposition of iron pyrites and organic matter in the shales.

3. Witteberg Series.

This series consists of sandstones, quartzites, and shales. The sandstones and quartzites are in thicker groups than those of the Bokkeveld beds, and occasionally contain thin beds of white quartz pebbles. They are, as a whole, of a more reddish and yellow tint and more micaceous than the arenaceous sediments of the Table Mountain Series, and are much less massive. Certain bands, however,—particularly the quartzite which occurs at the bottom of the series in the eastern parts of the outcrop—weather out in large white slabs and boulders. The shales are green, dark grey, red and blue in colour, and are mostly very micaceous and sandy. In the Eastern Province black carbonaceous shales occur. The chief fossil yielded by the beds is the peculiar plant form *Spirophyton;* in addition, rather poor specimens of plants belonging to the following genera have been recorded, mostly from the Eastern Province:— *Didymophyllum*, *Selaginites*, *Lepidodendron*, *Lepidostrobus*, *Halonia*, *Knorria*, *Sigillaria*, *Stigmaria*, *Cyclostigma*, *Bothrodendron*. The identification of some of these forms is, however, doubtful. No animal remains have been recorded, with the exception of the doubtful Eurypterid *Hastimima* and a fish-spine.

The maximum thickness of a series is 2500 feet (762 m). The northern boundary is a denuded one, as is the case with the Bokkeveld Beds. In the south, the beds form several important ranges of mountains on the southern border of the Karroo; and there is a large area of hilly ground formed by them to the south of the Worcester fault. Eastwards they form lines of hills that are peneplaned at a height of about 2600 feet (792 m) above sea-level, and the flat-topped ridge called the Zuurbergen; between Grahamstown and the coast to the east they are peneplaned and partly covered by Tertiary deposits. They do not occur in Pondoland or Natal.

South of the Langebergen the Witteberg beds are less quartzose and coarse-grained than to the north; the change in them is similar to that noted in the Bokkeveld beds as they are traced southwards. Similarly, to the east the shale bands seem to become more prominent, and the sandstones are more quartzitic and rather finer-grained. The absence of marine organisms is an argument against the marine deposition of the beds. The sea in which the lower half of the Bokkeveld series was deposited seems to have been replaced by a body of fresh-water which, from the evidence afforded by frequent ripple-marking and false-bedding, must have been shallow.

The Witteberg beds are of no economic importance. They give rise to poor soils, even in the eastern part of their outcrop where they receive a fair rainfall. In that part of the country they are clothed with a coarse type of vegetation; but westwards they give rise to barren tracts of land. Coaly shales have been prospected for coal, but without success.

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8. The Karroo System.

By

A. W. Rogers and S. H. Haughton.

The Karroo formation occupies some 240000 (621360 qkm) of the 472347 square miles (1222906 qkm) comprising the Union. It is intrinsically the most interesting stratigraphical group in the country, and it is extremely important economically on account of the coal in it, which occurs chiefly in Natal, the Transvaal and the Northern Orange Free State. The main area occupied by the Karroo beds stretches 800 miles (1287 km) from Karroo Poort in the south-west to the Middelburg District in the Transvaal, with a greatest width of 370 miles (595 km) between Kimberley and East London (see Fig. 31). Excepting 190 miles (306 km) in the south-east, between the Peddie district and eastern Pondoland, where it meets the ocean, and a narrow strip east of Vryheid, where a connection with the Lebombo mass still remains, the main area of the formation is surrounded by older rocks. It is a synclinal region with very low dips on the north-west, north and east, while in the south-west and south the beds dip steeply and are folded.

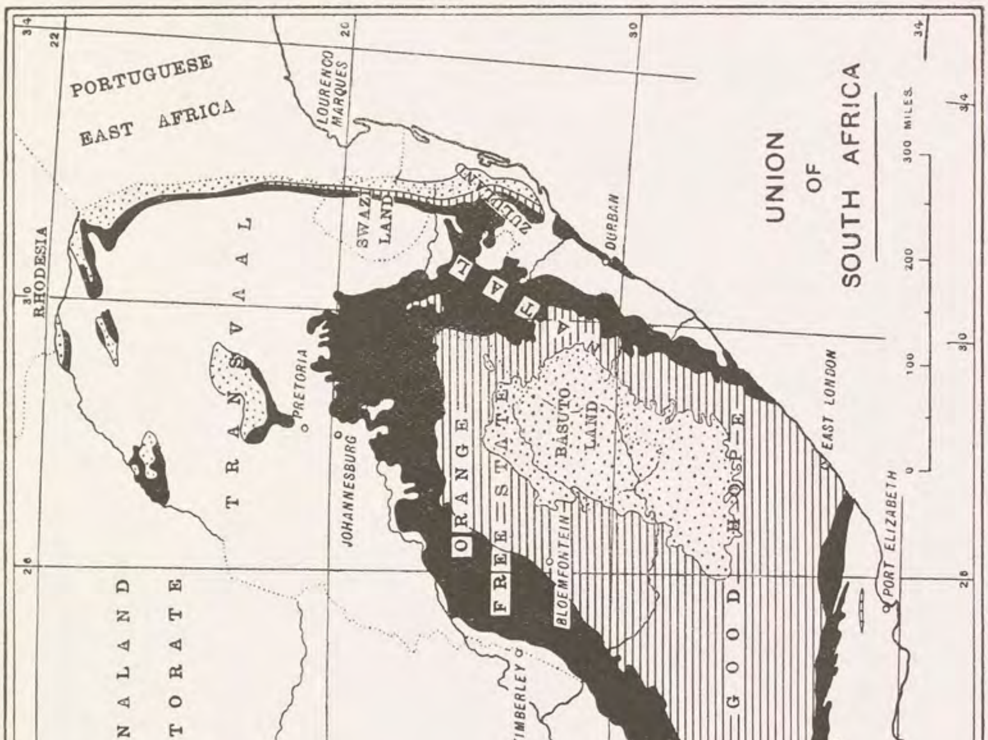

Fig. 31. Outline Map showing the distribution of the Middle and Upper portions of the Karroo System.

Though this synclinal region is probably the area in which the Karroo beds attained their greatest thickness, its present outline is far from their original limit, which lay beyond the Union. Extensive outliers occur in the Kalahari, the Transvaal Bushveld and the Limpopo Valley; while in the Lebombo region a strip of Karroo beds dips eastwards, passing unconformably under younger rocks for over 400 miles (644 km). The small outliers in Namaqualand, the Folded Belt and Natal are important for the evidence they give of the former extension of the system.

From Karroo Poort in the west to the coast of Peddie, a distance of 440 miles (708 km), the Karroo beds lie in apparent conformity upon the Witteberg Series, and this apparent conformity is seen as many as eight times along a section of 20 miles (32 km) length across the strike in the Willowmore district, where the outcrop is repeated by folding. In the Tanqua Karroo, 40 miles (64 km) north of Karroo Poort, the Lower Dwyka shales have disappeared, and the tillite rests unconformably upon Witteberg beds, while to the north they come to lie upon lower and lower horizons of the Cape system and finally, in Calvinia, upon the presumably pre-Cambrian sediments and igneous rocks; these conditions are maintained throughout the northern and eastern boundary of the Main area as far as the Nkandhla district, where the lowest beds of the Cape System again appear between the pre-Cambrian and the Karroo beds.

In the south-east no considerable unconformity or nonsequence has been recognised from the Lower Dwyka shales upwards as far as the top of the Red beds, but in places there is erosional unconformity at the base of the Cave Sandstone, which rests on Molteno grits at Glenelg in Maclear; and the Drakensberg volcanic beds, though first represented by lavas and tuffs interbedded with Cave Sandstone, often lie in hollows eroded in the Cave Sandstone, or even directly on the Red beds. North of latitude 28° ½ the Molteno beds disappear in the main area, and the Red beds rest upon the Upper Beaufort; whether Molteno beds are represented in the Bushveld and Limpopo outliers is uncertain. In the Transvaal and northern Natal the Beaufort and Ecca beds are much reduced in thickness, but the Middle Ecca in those regions is the important coal-bearing formation of the Union; the Beaufort beds thin out in the south-eastern Transvaal.

1. The Dwyka Series.

By

A. W. Rogers.

The Lower Dwyka Shales are a group of shales, sandy shales and quartzites lying conformably on the Witteberg beds throughout the south of the Cape Province. Their thickness ranges from some 500 to 1400 feet (150 to 427 m). The arenaceous beds increase in importance towards the east on the north side of and amongst the Cape ranges, being conspicuous near Mount Stewart. Black carbonaceous shales occur in the south of Somerset East. Though impressions of plant stems have been found in these shales at a few places, and plant tissues are recognisable in thin sections from a calcareous layer south of the Zuurberg, no determinable fossils have been obtained from the formation. The Lower Dwyka shales are overlain by the tillite, the transition generally taking place within 2 or 3 inches (5 or 7.6 cm) by the appearance of large grains or small pebbles in the shaly or arenaceous beds, but at places there is a sharply defined plane between the two. In Swanepoel's Poort and a few other places isolated pebbles and boulders are seen as far as 100 feet (30.5 m) from the top of the shales.

The Dwyka tillite is typically a hard blue sandy mudstone with boulders and pebbles of a variety of rocks scattered through it at random; the pebbles are often striated and flattened on one or more sides. Beds of boulders are occasionally found, and layers of grit and small pebbles are abundant in some areas; lenses of quartzite up to 30 feet (9.1 m) in thickness, occur in the southern tillite, representing contemporaneous sands; other smaller masses of quartzite are probably inclusions of sediment dropped in a frozen state by ice.

The extent of the exposures of the Dwyka tillite in the Union can be judged from the fact that the total length of the zone of outcrop round the main area of the Karroo beds is 1400 miles (2253 km), while it is in places 60 miles (97 km) wide in the north-west (see Fig. 32).

North of latitude 33°, where it lies unconformably on its floor, the thickness varies within short distances according to the shape of the floor; it is frequently absent in the Transvaal, where conglomerate derived from it may take its place, occasionally enclosing large erratics which still show striae. North of latitude 28° the tillite was partly removed by denudation before the deposition of the Ecca beds. In the south, where it is thickest (up to 1400 ft. = 427 m) the tillite is seen in suitable exposures to be bedded, though the thick bodies of rock between the bedding planes made conspicuous by weathering are not laminated. It is believed that the southern tillite was deposited in water by floating ice, both the floating end of land ice and icebergs; at Elands Vlei (Tanqua Karroo) there is a boulder-pavement, tillite furrowed by moving ice and studded with boulders pressed in and striated in the same direction as the furrows; the pavement is overlain by tillite very like the rock of which the pavement is the upper surface. Though the evidence is convincing that the tillite north of latitude 32° was formed on land while to the south it was laid down in water, there is as yet no other indication of the position of the change in conditions than the occurrence of unconformity in about latitude 33°. There are thick bodies of shale and pebbly shale interbedded with the southern tillite but their northern limit is not known precisely.

The movement of the ice, as shown be the direction of striae on the floor of the northern tillite and the distribution of boulders from known sources is indicated in Fig. 32. DU TOIT concludes that four masses of land-ice, in Namaland, Griqualand West, the Central Transvaal and on lost land east of Natal, were concerned in producing the effects observed within the Union. Of these effects the striated floor seen passing under tillite in the valleys of the Vaal and Modder Rivers in the Kimberley region is the most striking, though less spectacular instances of similar phenomena in Natal, the Transvaal, and in the northern Cape Province are very numerous.

The Upper Dwyka Shales are generally sharply seperated from the tillite on which they rest in the western and southern Karroo, but in the north of the Cape Province intercalations of glacial beds occur in them and they disappear in the Orange Free State, Transvaal and Natal. They are thinly bedded greenish and grey shales, black shales and thin flagstones, ferruginous and carbonate rocks, and cherts. In the southern and western Karroo a bed less than 2 feet (0.61 m) thick of chert is continuous for scores of miles and is taken as the uppermost bed in the series. The black shales weather white, and in dry regions make a conspicuous white band through the country. Nodules and lenses of phosphate of lime are abundant, in the Upper Shales, especially below the White Band, and similar nodules have been found in the tillite.

Obscure minute spheroidal bodies are visible in some thin sections of the phosphatic rock but their organic origin is uncertain. In regions so far apart as Kimberley, Calvinia, the Tanqua Karroo and Laingsburg specimens of the small aquatic reptile *Mesosaurus* have been found in the White Band or the beds close to it, the fish *Palaeoniscus*, the crustaceans *Pygocephalus* and *Anthrapalaemon* and the plant *Lepidodendron* occur in the Upper Dwyka Shales within the Union; marine mollusca and an echinoderm have been found in South West Africa.

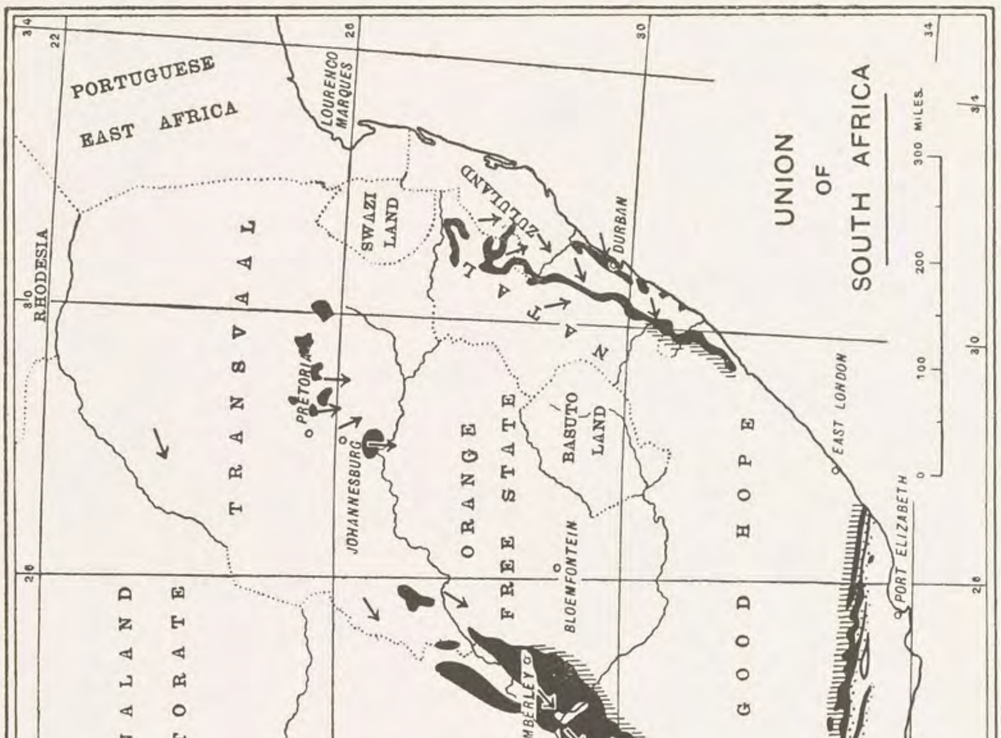

Fig. 32. Outline map showing the outcrops of the Dwyka Tillite (solid black) and direction of glacial striae on floor; also (diagrammatically) the distribution of the Lower (stippeled) and Upper Dwyka Shales (vertical lines).

2. Ecca Series[1].

By

S. H. HAUGHTON.

The beds of the Ecca Series are exposed in all four Provinces of the Union, lying around the edge of the Karroo Basin, and, along its southern border, involved in the folded region.

In the south-western part of the Orange Free State and in the north of the Cape Province from Petrusville westwards to Calvinia the formation has a thickness of over 2000 feet (610 m) and forms a wide belt of country. Here it consists almost entirely of bluish and greenish shales which, toward the summit of the formation, become rather flaggy. Calcareous concretions are abundant. Rarely, silicified wood is found; and from near Calvinia are well-preserved and abundant tracks of invertebrates and small amphibia. No other fossils are known from this belt of country.

From Calvinia the outcrop takes a southerly direction and sandstones begin to make their appearance, especially a little above the middle of the formation; green and purplish mudstones replace much of the blue shale, and fossil plants begin to occur—chiefly *Gangamopteris*, *Glossopteris*, and *Phyllotheca*. In the Klein Roggeveld the thickness has increased to 3500 feet (1067 m). At Laingsburg shales predominate in the lower and upper portions of the formation and sandstones in the middle. The passage from the Ecca Beds into the Lower Beaufort Beds is a gradual one all along the southern border of the Karroo, and in the absence of a "marker" at the junction of the two formations it is difficult to measure thicknesses with accuracy. South of Aberdeen the Ecca Beds, now predominantly arenaceous with subordinate mudstones and shales and lenticles of limestone, are considered to be 6000 feet (1829 m) thick. Along this southern belt the sandstones are hard, dark-coloured or mottled and medium- to fine-grained felspathic rocks, weathering yellowish or red. The shales are hard, and often break up into long roughly prismatic fragments. Ripple-marked surfaces are common; false-bedding and peculiar inverted and twisted bedding on a fine scale, similar to that described from the Keuper of England by BERNARD SMITH or from the recent Alluvium of the Orange River by ROGERS, are characteristic in this stretch of country. *Glossopteris*, *Schizoneura*, *Phyllotheca* and silicified wood, tracks of small invertebrates, fish-scales, and bones of two reptiles (*Archaeosuchus* and *Eccasaurus*) are the only fossils recorded from this belt.

In Pondoland, Natal and the South-Eastern Transvaal DU TOIT has divided the Ecca Series into three sub-divisions. The Lower Ecca Beds are soft blue shales, 1400 feet (427 m) thick in Pondoland and thinning gradually northwards until they are 800 feet (244 m) thick at the Tugela River. From there northwards the diminution in thickness is much more marked, until at Ermelo, and beyond, the shales are absent, and the Middle Ecca Beds rest unconformably on Dwyka or older rocks. The Middle Ecca Beds begin in the south as a sporadic bed of hard grey sandstone, and thicken as they are followed northwards from under 300 feet (91 m) at the Natal border to a maximum of 1700 feet (518 m) near the Tugela, lessening again northwards to a thickness of about 1000 feet (305 m), which is probably the maximum thickness over the Southern Transvaal. In the extreme south the Middle Ecca Beds are almost wholly arenaceous, with very subordinate flagstones and micaceous shales, the softer beds being fine-grained felspathic sandstones and the harder ones coarse white false bedded grits and arkoses, containing an abundance of fresh white orthoclase and microcline in angular fragments (occasionally well-rounded ones occur) often up to three-quarters of an inch (= 1.9 cm) across, with large

[1] The name "Ecca" comes from the Ecca Heights near Grahamstown, where the beds are well exposed.

irregular grains of quartz. Traced northwards, this group breaks up gradually into a series of similar members parted by thick bodies of grey flagstones and soft very micaceous sandy shales with thin whitish fine-grained sandstones, blue or black shale being rare. Large calcareous concretions are common in the grits and sandstones and layers of calcareous sandstone or impure limestone occur in the upper part of the group. Oval ferruginous concretions containing fish-remains are fairly abundant in one zone of dark shales. Worm burrows are common in the flags and sandstones. Stratified iron ores, in thickness from one to five feet, occur at several places, not improbably all on the one horizon.

The coals of Natal and the Transvaal occur in the Middle Ecca Beds. In the lower half of the group in Natal the coals are anthracitic and unworkable. The workable coals in the area between Pomeroy and Vryheid occur just above the middle of the group. In northern Natal the coal horizon is a full 700 feet (213 m) above the base of the group; whilst, further north, seams are more numerous and are present not only at the summit but near the extreme base of the beds. In the Eastern Transvaal basins the seams are generally present in the lower 200 feet (61 m) of the beds; but here there is an unconformity between the Middle Ecca Beds and the rocks on which they lie, and the base of the group may not be present. In the Southern Transvaal and south-westwards into the Orange Free State the coal-bearing strata rest unconformably upon Dwyka Tillite. Torbanite occurs in the Middle Ecca Beds in the south-eastern Transvaal, chiefly in the districts of Ermelo and Wakkerstroom, in the upper half of the group.

The fossil flora of the Middle Ecca of this region shows an intermingling of the southern *Glossopteris* flora with northern forms such as *Sigillaria*, *Bothrodendron*, *Lepidodendron*, *Psygmophyllum*, etc. At Vereeniging large tree-stumps closely resembling European *Cordaites* have been found in situ.

The Upper Ecca Beds consist of uniform soft bluish shales varying in thickness from 500—800 feet (152—244 m) in Natal. They contain frequent greyish concretionary nodules, lenticles, or impersistent layers fairly rich in phospate of lime.

In the North-West Transvaal boring has proved the existence of Lower and Middle Ecca Beds in the Waterberg District. The Lower Ecca consists of black barren shales, the Middle beds of about 120 feet (36 m) of sandstones with a group of coal-seams followed by 230 feet (70 m) of alternating thin coals and black shales, of which about two-fifths are actually coal. The southern boundary of this basin abuts abruptly against the much older Waterberg System.

In the South-West Transvaal dark Lower Ecca Shales 100 feet (30.5 m) thick lie between the Middle Ecca sandstones and grits and the Dwyka Tillite; and it is probable that there is a change along the western border of the Orange Free State analogous to that seen in going southwards through Natal into Pondoland.

In the Southern Kalahari Ecca beds occur in an exceedingly flat syncline which is masked by superficial deposits, and consist of alternations of sandstone and shales lying on a calcareous grit. The sandstones are generally calcareous, the shales green, red and purple in colour. They follow conformably on shales which overlie the Dwyka Tillite. The chief exposures occur along the Molopo River. This facies is quite different from that south of the Orange River.

The change of facies and the diminishing thickness of the Ecca Beds as one proceeds northwards in the Cape Province point to the south of the present continent as being the area from which the sediments in the Cape were derived. In Natal, however, the source seems to have lain to the north-east, in an area which now forms part of the Indian Ocean.

3. Beaufort Series.

By

S. H. HAUGHTON.

Lithologically, the Beaufort Series has been divided into three, known as the Lower, Middle, and Upper Beauford Beds. On palaeontological grounds, however, further subdivisions have been made, as follows:—

6. *Cynognathus* zone	Upper Beaufort Beds
5. *Procolophon* zone	
4. *Lystrosaurus* zone	Middle Beaufort Beds
3. *Cistecephalus* zone	Lower Beaufort Beds
2. *Endothiodon* zone	
1. *Tapinocephalus* zone	

Owing to the difficulty of collecting reptilian remains and their scarcity over fairly large areas, the palaeontological sub-divisions must remain of secondary importance as compared with the lithological grouping. Nevertheless, they are well-defined in some parts of the Karroo area and, as more extensive collecting proceeds, their geological importance will doubtless be enhanced.

The Series covers a large area in the Cape Province and Orange Free State and a considerable portion of Natal.

Lower Beaufort Beds. In the northern part of the Cape Karroo the argillaceous beds of the Ecca give place suddenly to massive yellow-weathering, felspathic sandstones of the Lower Beaufort. These sandstones alternate with thick bodies of blue, green and occasionally red or purple mudstones and shales. The thickness of the beds increases in a southerly direction, so that in the Western Karroo there are probably between 7000 and 8000 feet (2133 and 2438 m) of sediments assigned to this division. The base in the Western Karroo is a somewhat doubtful one, as the sandstones of the *Tapinocephalus* zone are fine-grained, hard and dark green, weathering red, and similar to the sandstones of the underlying Ecca. The *Endothiodon* zone in the west is characterised by bluish and greenish well-bedded shales with thin, softer, yellow-weathering sandstones; whilst the beds of the *Cistecephalus* zone are mainly bends of greyish and greenish shales and mudstones separated by beds of sandstone—which is either a rather coarse-grained thickly-bedded rock ("defining sandstone") or a finer-grained thinner-bedded sediment ("intermediate sandstone"). False-bedding and ripple-marking are common in the sandstones throughout the subdivision, and local small unconformities are abundant. At the base of the sandstones beds of mud-pellet conglomerate containing rolled and broken bones are often found. In the lowest zone in the south-western Karroo concretionary nodules and lenticles of brown-weathering bluish limestone are abundant, and the shales often contain small veins and masses of pipe-like rods of pink or white chalcedony. The limestone lenticles may reach a length of 100 feet, but are rarely more than 2 feet thick. They show irregular banding and are pierced by small cylinders of chalcedony, and underlying each is a thin layer of pink, green-weathering chert. Occasionally these lenticles are associated with bones of Pareiasaurian reptiles; and the probability is that they are of organic origin, although no definite organisms have as yet been observed in them. Purple shales occur both in the *Tapinocephalus* and *Cistecephalus* zones, but are much rarer in the middle zone.

In the Transkei the thickness is from 4500 to 5000 feet, and it diminishes in a northerly direction until it is not more than 1100 feet in Northern Natal (Fig. 33). With this diminution in thickness occurs a lithological change. The cream or drab fine-grained sandstones get whiter and coarser in grain and better defined, until in northern Natal they are thick felspathic grits with little quartz-pebbles and occasional inclusions of granitic rocks. The argillaceous beds change from blue and green mudstones to thin sandstones and dark fairly well laminated shales. Very fine-grained carbonaceous shales come in, carrying plants, *Estheria*, and fish-shales, and are sometimes accompanied by thin impure coals. The anthracitic coals of the St. Lucia coalfield in Zululand are probably of Lower Beaufort age. In the S. E. Transvaal the Lower Beaufort Beds consist of massive sandstones alternating with soft shales and mudstones which often contain calcareous nodules. Numerous thin seams of coalbearing beds of Komati Poort are at least partly of Lower Beaufort age[1].

In the western part of the Orange Free State fine-grained sandstones and blue shales and mudstones occur; but in the north and north-east of that Province coarse grits take the place of the sandstones—a change of facies similar to that seen in Natal. The fossils occur mainly in the south-western Karroo, and it is only here that the limits of the palaeontological zones can be well defined. The assemblage of Permian Reptiles and Amphibia known from this area is an unique one, prolific both in species and numbers. From the *Tapinocephalus* zone some 45 genera of Reptiles have been described, belonging to the *Cotylosauria*, *Therapsida*, *Diaptosauria* and *Testudinata*. The chief forms are large herbivorous *Pareiasauria*, large carnivorous *Titanosuchids* and herbivorous *Tapinocephalids*, small *Dicynodonts*, and the more mammal-like *Therocephalia*. The subsequently more important *Gorgonopsia* begin in this zone; and the interesting Testudinate *Eunotosaurus* and lizard-like *Broomia* also occur. The heavily-built *Pareiasauria* usually occur as articulated skeletons in the mudstones and shales with no signs attched to them of post-mortem transportation. The small *Dicynodonts* are fairly frequently found as groups of skeletons; but the remainder of the forms are generally encountered as isolated skulls or disarticulated groups of associated bones. An Amphibian, *Rhinesuchus*, occurs in the zone; some Palaeoniscid fish and small lamellibranchs (*Palaeomutela*) complete the fauna of the beds. *Glossopteris* and *Phyllotheca* occur very sparingly.

The fauna of the *Endothiodon* zone is known mainly from the areas around Beaufort West, Graaff Reinet, and Fort Beaufort, but fossils probably belonging to that zone have been found at East London. The type genus is the peculiar Anomodont, *Endothiodon*, which is associated with a number of medium-sized species of *Dicynodon* and allied genera, small *Endothiodontidae*, some *Gorgonopsia* and a number of *Therocephalia*. The large Pareiasauria of the preceding zone are replaced by smaller members of the same group; and the Titanosuchids and Tapinocephaloids have entirely disappeared.

The *Cistecephalus* zone contains a very important fauna, including a number of mammal-like Therapsids which lead to the advanced types of the Upper Beaufort Beds. Small *Pareiasauria*, numerous Dicynodonts (including the zone fossil *Cistecephalus*), advanced *Therocephalia* and *Gorgonopsia*, and the very important early Archosaurian *Youngina* form the majority of the Reptiles. Several Amphibian genera occur; as do a few specimens of lamellibranchs and a small Crustacean *Cyzicus greyi*. Plants are rare, *Glossopteris* being the only well-authenticated genus. The chief localities are in the central portion of the Cape Karroo; but fossils of the zone are found at Modder River to the east of Bloemfontein and along the Orange River near Bethulie.

Middle Beaufort Beds. This sub-division is well defined in the Cape Province, Orange Free State, and Natal. Its thickness ranges from 1000 feet (305 m) in the

[1] Mr. W. Wybergh found (in 1927) *Gangamopteris* near the base of the Coal Measures at the junction of the White Umbelusi and Usulitwana Rivers, Swaziland, which indicates the Ecca age of the beds there.

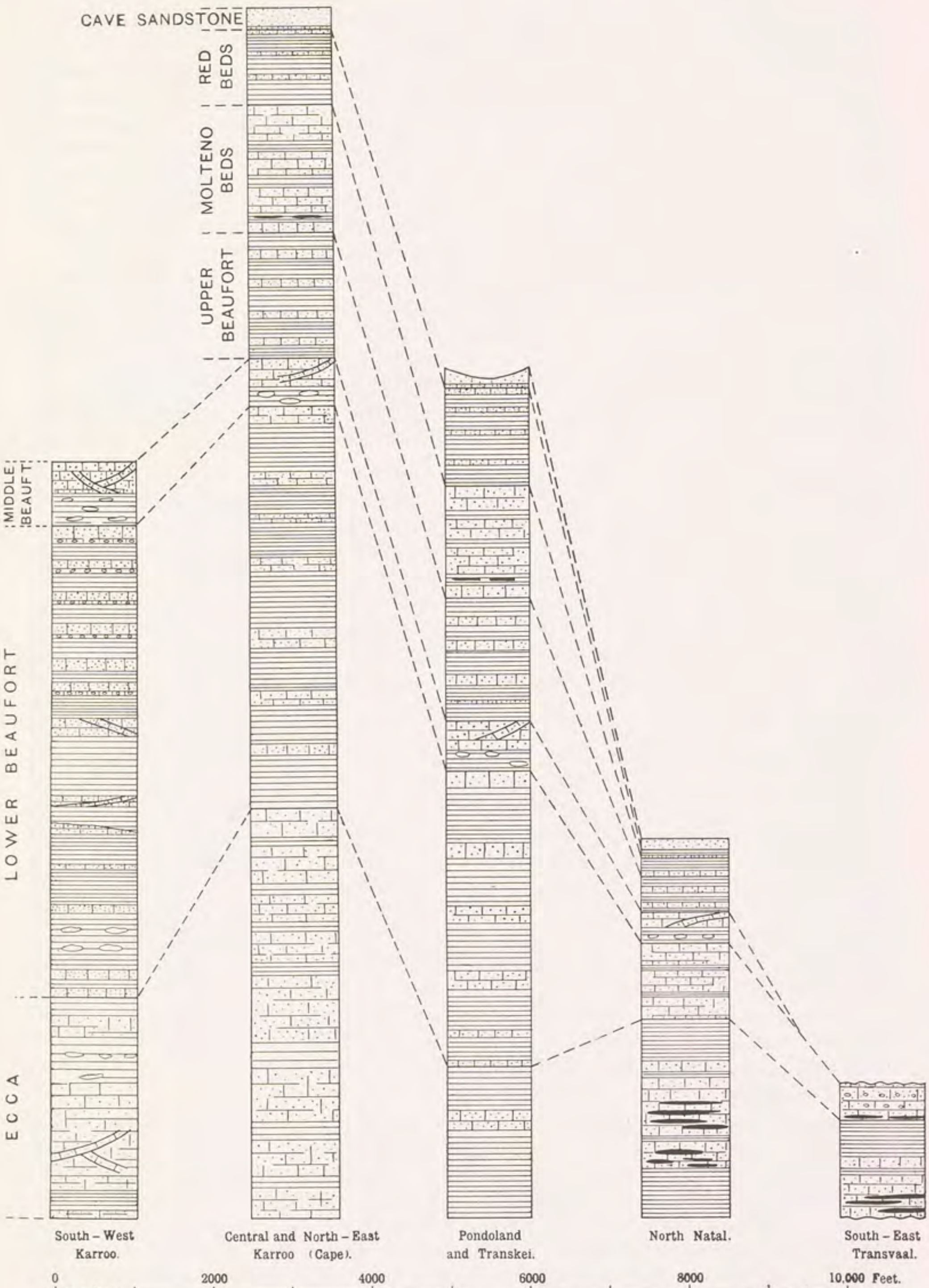

Fig. 33. Comparative Vertical Sections of the Karroo Succession (Stormberg Volcanic Series omitted) in different parts of the Union.

west (Rosmead and Naauwpoort) to a uniform 500 feet (152.5 m) at Bulwer in Natal and northwards, being about 800 feet (244 m) in the Transkei. The lower portion consists of bright-red, purple and green shales and clays; the upper portion of well-defined yellow massive sandstones separated by thin shales and mudstones. Traced northwards these sandstones become rather coarser in grain and more massive. Calcareous concretions are common in the shales and many of the fossils occur in such concretions. A prominent feature of the beds in the Central Cape Province is the amount of hard mud-pellet conglomerate with fragments of bone. False-bedding and ripple-marking are prominent characteristics of the sandstones, and the smooth surfaces show numerous "mud-runs", sometimes simulating tracks.

The zone fossil *Lystrosaurus* occurs abundantly throughout the area where the beds are exposed. It is an ally of *Dicynodon* but was specialised for digging in mud with its powerful tusks in search of food, the nostrils having retreated to the top of the long downwardly-directed snout. In the south it is the only abundant fossil; but in the north it is associated with a small Amphibian *Lydekkerina* and early Cynodont reptils such as *Ictidopsis* and *Glochinodon.* The large Amphibian *Rhinesuchus* (*Uranocentrodon*) *senekalensis* also occurs in this zone.

Upper Beaufort Beds. This subdivision extends in a belt from Burghersdorp through Tarkastad and Queenstown eastwards through the Transkei, then northwards through Natal along the flanks of the Drakensberg into the Orange Free State as far north as the neighbourhood of Memel, and southwards through the Free State to Aliwal North. It is thickest in the south and south-west (200 feet = 610 m) and thins out northwards to 600 feet (183 m) at Harrismith and 150 feet (46 m) near Memel. The beds consist of prominent widely-spaced yellow or buff-weathering fine or medium-grained, often blue, felspathic sandstones alternating with blue, red or purple and green clays and shales. The deep reddish shales show streaky layers and large spots of pale greenish-blue tint. Red calcareous concretions are common. The sandstones are of two types. One type consists of fine well-rounded grains of quartz (usually white with some reddish and occasionally fretted surfaces) containing lumps of purple mud, and showing but very slight evidence of current bedding. This type might conceivably have been formed by the quiet settling of wind-blown sands in pools, the lumps of mud having been dropped from floating logs or having been carried into the pool on the feet of amphibia or reptiles; the type is predominant at the base of the subdivision. The other type is much more obviously bedded and cross-bedded, and occasionally becomes violet in colour. The clays contain long flattened lenses of fine-grained sandstone with sparkling quartz-faces when fresh, as well as patches of greenish coarse sandstone with concretions containing numerous plant fragments and small pieces of bone. These features of the clays are more common in the lowest part of the beds (*Procolophon* zone). Near the summit of the formation is a persistent band of dark greenish ferruginous sandstone, which weathers black. Clay-pellet conglomerates are common. There is very little lithological variation over the known extent of the outcrop.

Two zones are recognised, a lower *Procolophon* zone and an upper *Cynognathus* zone. The *Procolophon* zone is a very thin one, but its characteristic fossils have been found along the western side of the outcrop from near Queenstown to the north side of the Orange River, occurring in dark red marls with numerous calcareous concretions and nodules interbedded with thin sandstones, which have irregularly rippled and hummocked surfaces covered with thin green mud and clay-pellet conglomerate. The Cotylosaurian *Procolophon* is the chief fossil. The Archosaurian *Proterosuchus* occurs in the zone, as well as the Amphibia *Capitosaurus* and *Trematosaurus*.

The *Cynognathus* zone has yielded an abundant flora and fauna, especially in the west and south west. The large *Kannemeyeria* is the last surviving Dicynodont. Mammal-like reptiles belonging to the Cynodonts and *Bauriamorpha* attain a splendid and diverse development. The large *Erythrosuchus* and the small *Euparkeria*, *Howesia* and *Mesosuchus* are prominent Diaptosaurian genera; whilst the pre-lacertilian *Palacrodon* also occurs. A number of large Stereospondyl Amphibia have been found, long-headed forms like *Capitosaurus* and short broad-headed genera such as *Batrachosuchus*. The supposed mammal *Tritylodon* is almost certainly from this zone in the Orange Free State.

A fish-fauna, including the shark *Hybodus africanus*, the mud-fishes *Ceratodus capensis* and *C. ornatus*, and a number of Ganoids (*Helichthys*, *Oxygnathus*, *Dictyopyge*, *Cleithrolepis*, *Hydropessum*, *Pholidophorus*) are known from a few localities, where individuals occur in fair abundance.

The flora shows a mixture of such forms as *Glossopteris*, *Danaeopsis*, *Odontopteris* and *Stigmatodendron* with the typically Molteno genera *Thinnfeldia* and *Taeniopteris*. The plants are for the most part preserved in the sandstones and details of structure are often not very clear.

Viewing the Beaufort Series as a whole, it can be seen that the thick succession of argillaceous and arenaceous rocks must have been laid down in a gradually sinking area, the geosyncline being most actively developed in the south-west. The deposits cannot be looked upon as lacustrine, and the whole area must have been one of swamps and marshes, low-lying ground possibly fed by large and sluggish streams carrying material from the comparatively low rims of the basin. The fauna—apart the few fishes, small lamellibranchs and sporadic crustacea—was a terrestrial one, composed of heavy-limbed, ponderous, marsh-dwelling forms or of lighter-limbed animals whose habits probably were similar to those of the modern lizards. The sediments are of such a fine-grained nature and the mode of occurrence of the skeletal remains is such that the latter cannot have been transported by water far from the places in which they died. The presence of cross-bedding, ripple-marks, mud-pellet conglomerate, "mud-runs", and the like all point to conditions bordering between subaqueous and terrestrial, and oscillating rapidly from one to the other; the whole being a series of vast flood-plain deposits modified by wind-action. The coarser nature of the Lower Beaufort Beds in Northern Natal, and the occurrence there of grits and pebble-beds, indicate the proximity of the area to one of the higher land-masses from which the sediments were derived. Together with this coarseness of material goes the existence of coal-seams in the Lower Beaufort Beds of that area, of Zululand, and of the Komatipoort down-warped mass.

4. Stormberg Series.

By

S. H. Haughton.

The Stormberg Series covers the whole of Basutoland and a belt of high country right round that Territory, forming an irregularly-oval outcrop in ground plan extending for nearly 300 miles (380 km) in a N.N.E.—S.S.W. direction and having a maximum E.—W. width of about 150 miles (240 km). Outliers occur, to the south in a down-faulted area near Port St. John's, and to the north as several patches in the Transvaal, the most extensive being that of the Springbok Flats, and the Lebombo range is made of them.

The Series is divided into four components:—

4. Drakensberg Volcanics.
3. Cave Sandstone.
2. Red Beds.
1. Molteno Beds.

Molteno Beds.

This division is well developed in the south of the main area, but thins out northwards, and is not found north of Bezuidenhout's Pass, near Harrismith, Orange Free State. At its most southerly outcrop it is 2000 ft. (610 m) thick, but it gradually thins to about 140 feet (42.7 m) along the northern Natal Basutoland border and then disappears. Its base is everywhere conformable to the underlying Upper Beaufort Beds.

The beds consist of sandstones, shales and mudstones which are gray, greenish or bluish in colour, and lack any prominent calcareous portions. In the south there is a great preponderance of arenaceous beds, but towards the north the argillaceous deposits play a more important, but still subsidiary, part. The sandstones are coarse in grain, loose textured, and contain abundant felspar. In the south they are coarser than in the north. They occasionally contain nodules formed by the oxidation and hydration of iron pyrites. Occasional conglomerates occur, containing irregular boulders and pebbles, which sometimes rest on coal-seams and are partly imbedded in overlying sandstones. Such pebbles are most abundant to the south-west. One feature of the Beds is the occurrence of "glittering sandstones", in which the original quartz grains are coated with a later deposit of quartz with more or less crystalline faces which reflect light well. Workable coal-seams occur in the Molteno, Dordrecht, and Indwe areas. The coals are thin, and alternate with thin black shales, occupying detached areas—a fact due in part to non-deposition of material and in part to contemporaneous erosion.

Plant remains are fairly abundant in the lower half of the Beds, the chief genera being *Thinnfeldia*, *Taeniopteris*, and *Baiera*, etc. *Glossopteris* also occurs. No animal remains have yet been described from this division.

Red Beds.

The thickness of this division is very variable. The maximum thickness is 1600 feet (488 m), but between points about 10 miles apart, the thickness may vary by nearly a thousand feet. Apart from these local variations, there is a general thinning out northwards and eastwards, the thickness in the north-east of the Orange Free State being only 160 feet (48,8 m). Where the Molteno Beds are present the Red Beds overlie them conformably; where the former are absent the Red Beds lie upon the Upper Beaufort Beds, but without any angular discordance.

The beds consist of brilliant purple and red mudstones and shales with red sandstones, and yellow and white fine-grained felspathic sandstones forming bands up to 30 ft. (9.1 m) thick, which sometimes lie upon eroded surfaces of the softer beds. "Glittering sandstones" occur near the base in some districts. Calcareous nodules and concretions are fairly abundant, especially in the mudstones and occasionally coalesce to form beds of limestone; but pebbles are very uncommon. As a general rule, the sandstones become finer-grained as one ascends in the division. Bands of clay-pellet conglomerate are not uncommon at the base of the sandstone layers. The upper surfaces of the mudstones sometimes carry sun-cracks, worm-tracks and reptilian foot-prints.

In the central Transvaal, the Red Beds are represented by a basal bed of coarse grits and pebble-bands followed by layers of red marl or shale; they rest unconformably upon denuded surfaces of granite or folded pre-Cape sediments or upon the Middle Ecca "Coal-Measure Grits".

In the Komatipoort area, the basal portion of the "Bushveld Sandstone" consists of calcareous sandstones, underlain by thin-bedded, soft, dark-red and greenish sandy shales and marls, the red colour predominating. These are probably equivalent to the Red Beds of the Cape Province. In the Northern Transvaal somewhat similar red and purple sandy shales and soft sandstones, calcareous in places, lie below the main mass of the "Bushveld Sandstone" and unconformably upon older rocks.

The chief fossils found are vertebrates—mainly Theropodous Dinosaurs belonging to the genera *Thecodontosaurus*, *Gyposaurus*, *Aristosaurus*, *Massospondylus*, *Aetonyx*, *Dromicosaurus*, *Plateosaurus*, *Gryponyx*, *Euskelesaurus*, *Gigantoscelus*, *Eucnemesaurus*, and *Melanorosaurus*, as well as an Ornithischian *Geranosaurus*. Some interesting Archosauria such as *Sphenosuchus*, *Notochampsa*, and *Pedeticosaurus* have been described, as well as some specialised Cynodonts—relics of the upper Beaufort fauna. Plants are very scarce, except for fossilised trunks belonging to *Rhexoxylon*.

Cave Sandstone.

The Cave Sandstone in the main area of Stormberg Beds is a massive fine-grained white or cream-coloured rock composed of sub-rounded to angular grains of quartz and felspar set in a cloudy and dusty groundmass. The felspar grains are but little decomposed and play a subordinate part to the quartz in the formation of the deposit. Flakes of mica, grains of zircon, garnet and rutile also occur. The deposit is of varying thickness, with a maximum of 800 feet (244 m), and in some places it is absent, the Drakensberg lavas resting directly and unconformably upon the Red Beds and even upon the Molteno Beds. Bedding-planes are but feebly developed, and then only in the basal and upper portions. Along the eastern edge of the Orange Free State the lower layers are red in colour and there is continuity of deposition from the Red Beds to the Cave Sandstone. The upper layers are sometimes intercalated with the basal sheets of the overlying lavas. One or two thin patches of finely-bedded greenish and bluish shale occur in the main body of the deposit.

In the Transvaal, the Cave Sandstone is represented by several outliers of the so-called "Bushveld Sandstone". This has many features in common with the Cave Sandstone; the rock from the more northerly of the outliers having more rounded and somewhat larger grains than those of the typical Cave Sandstone. A striking feature of the Cave Sandstone throughout the Union is the peculiar forms which result from its weathering—the outcrops being characterised by fantastically-carved pillars and by caves and overhanging shelters.

The fauna is a small one. Light-limbed cursorial reptilia such as *Thecodontosaurus*; *Gyposaurus* and *Notochampsa* occur in the sandstones; whilst the shale-patches have yielded insect wings, ostracods, *Cyzicus* and the Phyllopod *Lepidurus*. The fish *Semionotus capensis* is abundant at one or two localities. No plant remains, other than silicified trunks, have been found.

Mode of Deposition.

As a whole, the Stormberg Series was formed during a period of increasing aridity. The Molteno Beds were deposited under deltaic conditions in a climate which was intermediate in character between constantly rainy and intermittently rainy. The southern more arenaceous facies of the deposit represents the upstream portions; the northern, thinner and less coarse facies represents the downstream terminal beds. Land to the south (and possibly east) contributed the rock-waste which was deposited over the subsiding area to the north.

The red colouration of, and the somewhat unusual occurrence of carbonates in, the Red Beds, together with the whole assemblage of available criteria, lead to the conclusion that the Red Beds period was one of semi-aridity following in logical sequence from the intermittently rainy period of the Molteno Beds; that the aridity increased as time went on; and that the Beds themselves are flood-plain deposits.

The Cave Sandstone indicates a continuation of the climatic change in the direction of aridity. The typical form of the rock—the massive, un-bedded facies with angular and sub-rounded grains—has nearly all the features of an aeolian deposit such as the loess, and it is now generally considered as a wind-blown formation whose constituents were carried from the south northwards. In the type area the conditions were not absolutely arid; but to the north, in the Transvaal, there is a transition to a true desert sandstone, which reaches its full development—a "millet-seed sandstone"—in the contemporaneous Forest Sandstone of Southern Rhodesia.

The **Drakensberg** or **Stormberg Volcanic Beds**

By

A. W. Rogers.

These beds are preserved in three great areas within the Union; in Basutoland and the neighbouring high ground to the south-west and north; in the Springbok Flats of the Central Transvaal Bushveld; and in the Lebombo range and Limpopo valley. The small area of volcanic rocks discovered by boring in the Waterberg Flats affords a connecting link with similar basalts in the Protectorate, and the narrow strip south of Zuurberg near Algoa Bay is very important geologically. How far these different volcanic regions formerly extended and were connected may remain unknown, but the xenoliths of basalt found in certain breccia-filled necks in Carnarvon and neighbouring districts and in Griqualand West suggest a considerable extension to the west; the cliffs of the Drakensberg facing east point to former extensions there. In the Basutoland volcanic region and in the Transvaal Bushveld the outflow of lavas began before the deposition of the Cave Sandstone ceased, although in the Basutoland region the Cave Sandstone had been tilted and removed by denudation in places (e. g. east of Xalanga Peak) before the lavas covered it; thus pronounced earth-movements affected the country concurrently with the initiation of vulcanicity. The lavas are mainly augite-andesites and basalts. Tuffs and agglomerates are minor constituents of the group and are confined to the lowest thousand feet or so, the greatest thickness of the volcanic rocks being over 4000 feet (1220 m) at Mont-aux-Sources. In those parts of the region surveyed in detail over 150 necks have been found ranging in size up to more than five square miles. The vents have been found in the lower lavas and amongst the sedimentary beds below them; in some instances the vents are still partly covered by later flows of lava. They are filled with agglomerate, tuff, sandstone which filled the open vent before the deposition of the Cave Sandstone ceased, and doleritic basalt. The upper and by far the greater portion of the lavas were probably ground out from fissures. The fact that the existence of great volcanic vents has not been demonstrated in the long intervals between the Basutoland area and the Bushveld and Lebombo regions suggests that the explosive type of eruption was limited to those regions, if it occured in all three; up to the present, however, volcanic necks have been described only in and around the Basutoland region, where Dr. Gevers showed that they do not occur in beds lower than the Molteno and may have been due to thick intrusions amongst those beds believed to have been saturated at the time with connate water.

In contrast to the Basutoland region the volcanic areas of the Central Transvaal

Bushveld and the Waterberg Flats show few outcrops, and little detail is known of their structure. The lavas and tuffs seen there are types usual in the Basutoland region.

The Lebombo volcanic region stretches from Umfolozi in Zululand for 450 miles (724 km) northwards to the Limpopo, but it is continued far in Portuguese and Rhodesian territory. Comparatively little is known of this region, where activity was perhaps more pronounced and varied than in the Basutoland region. No vents have been described from it, but the thickness of the basaltic lavas has been estimated to be 6000 feet (1829 m), and they are succeeded by rhyolites and acid tuffs of perhaps equal or greater thickness. This volcanic area has a branch extending up the Limpopo valley, where its base is very uneven, resting on an apparently eroded surface of Cave Sandstone. In the western outliers normal basalt is believed to occur, but on the Messina road and east of it limburgite and augitite appear to be the main type of igneous rock, while nepheline basalt is widespread towards the east. All these volcanic rocks are cut by dolerite of the usual sort, but in view of the much later date attributed to similar alkali-lavas in Portuguese territory and the pronounced erosion of the Cave Sandstone at the base of the volcanic rocks in the Limpopo valley further examination is necessary before the Limpopo lavas can be accepted as contemporaneous with those of the Basutoland region.

Immediately south of the Zuurberg range near Algoa Bay there is a downfaulted area of Uitenhage beds 100 miles (161 km) long by 10 (16 km) wide in the west around which basalts, tuffs and sediments lie unconformably below the Uitenhage beds and in contact across a fault with Dwyka, Witteberg or Bokkeveld beds. The lavas and tuffs resemble those of the Stormberg region, except that analcite has been found in many of the Zuurberg basalts (as in some of the Limpopo lavas) but not elsewhere in the Drakensberg beds. In the south-western part of the Zuurberg region mudstones, marls and sandstones containing fragments of bone lie below the volcanic rocks, and they are believed to be Stormberg sediments. The importance of this outlier is that it supports other evidence which dates the folding in the Cape Ranges as previous to the Stormberg series, provides evidence for the pre-Cretaceous age of the Drakensberg lavas, and witnesses to the extension of volcanic activity at that time 150 miles (241 km) south of the known outliers in the Stormberg. The nearest known intrusions of dolerite lie 30 miles (48 km) to the north of the Zuurberg outlier.

5. The Dolerites.

By

A. W. ROGERS.

At a late stage in the deposition of the Karroo System or after its completion the whole of the South African region with the exception of the Folded Belt was invaded by more or less basic magma which solidified as dolerite and its differentiates. The intrusions have the form of dykes, inclined, curved and ordinary sills or sheets, and thick basin-shaped and dome-shaped bodies; no laccolite, cake-shaped body, with the strata arched over it, has been found amongst them. In the pre-Karroo formations the dolerite is chiefly in the form of dykes; in the great region of gently inclined or flat Karroo beds the intrusions are frequently sills, and the great masses of various forms are found chiefly in the north-eastern districts of the Cape Province, including the Transkei. Topographically the sills are the most important form of intrusion, for they give rise to many of the cliffs and table mountains of the interior as well as to waterfalls. The dykes have in many instances been found to cut sheets, though some of them have been traced into them so were evidently feeders. In the Karroo region north of latitude 32° ½ deep boreholes show as much as 25% of dolerite above the base of the Dwyka, and du Toit estimated the proportion of dolerite as 18—20 % in the region of the Karroo beds in Natal and Eastern Province of the Cape.

The youngest beds in which the dolerite is intrusive are the Drakensberg volcanic rocks, and the oldest beds known to contain detrital fragments from them are the Umgazana and the Embotyi beds in Pondoland, probably of Neocomian age.

The greater part of the dolerites are augite-plagioclase rocks with ophitic structure; olivine, or serpentine pseudomorphs after it, is often present; ilmenite and magnetite are always found, and there is generally some biotite. Micropegmatite of quartz and orthoclase is a usual constituent of those parts of the rock without olivine; hornblende and enstatite rarely occur. Glassy rocks are confined to thin bodies and the margins of some of the larger. Differentiation of post-intrusive data is marked in the great masses of Insizwa, Malongeni, Tabankulu, Tonti and the Ingeli in the Transkei, parts of one thick sheet made of dolerite elsewhere. The thick masses in these mountains range in composition from picrite through olivine-gabbro or norite to gabbro with quartz and orthoclase. In places at the contacts with the sediments below considerable quantities of sulphides have formed. More acid rocks than dolerite, quartz-diorites, granophyre and microgranite form minor intrusions in the Karroo region; these rocks often cut the dolerites, but were probably derived from the same magma by differentiation before their intrusion.

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9. Cretaceous System.

By
A. W. ROGERS and S. H. HAUGHTON.

a) Uitenhage Series.

Beds assigned to this series are developed in certain distinct areas in the southern folded belt of the Cape Procince. The type area is the country near Uitenhage (including parts of the valleys of the Zwartkops,Coega,Sundays, and BushmansRivers) and it is here that the series has its fullest development (see Fig. 34).

The basal group of the series is the "Enon Beds", which typically consist of white or red conglomerates formed of pebbles—chiefly of quartzite or quartz—up to eight inches in length embedded in a sparse sandy matrix; the pebbles are often indented or cracked by mutual pressure. Occasionally bands of conglomerate contain large boulders which may reach a length of 14 feet (4.27 m). In the north of the type area the Enon conglomerates pass upwards into the "Wood Beds", which consist of thick sandstones with lenticles of grit, coarse river-pebble conglomerates and occasional marly layers, which contain fossil plants—leaves and trunks, the chief among which are *Zamites recta*, *Cycadolepis jenkinsiana*, *Araucarites rogersi*, *Onychiopsis mantelli*, *Cladophlebis browniana*, and *Sphenopteris fittoni*. Large Dinosaur bones are recorded from the Bushmans River. These "Wood Beds" are well developed in the valleys of the Sundays and Bushmans Rivers. In the west of the type area the thick Enon conglomerates pass upwards into sandstones with pebbles, these into the so-called "Zwartkops Sandstone" with thin pebble bands, and this into the Variegated Marls of Uitenhage. In the extreme south-east (near Port Elizabeth) the basal beds of the series consist of a great thickness of grey, green and blue fresh-water shales and clays underlain by sandy beds.

The "Wood Beds" of the Sundays River and the "Variegated Marls" of Uitenhage pass upwards into the "Marine Beds"—a prominent mud-pellet conglomerate containing abundant *Cyprina* forming a passage-bed in the former area. The Marine Beds consist of bluish clays and buff sandstones and have yielded an abundant fauna, which is considered to be equivalent to that of the Oomia Beds of Cutch and to part of the Neocomian of Europe. The most common forms are *Astarte herzogi*, *Cyprina rugulosa*, *Exogyra imbricata*, *Gervillia dentata*, *Modiola baini*, *Perna atherstonei*, *Pleuromya lutraria*, several species of *Trigonia*, *Natica*, *Turbo*, and *Holcostephanus*, with numerous other and less abundant forms.

At places in the north and west of this basin a narrow strip of what are believed to be Stormberg beds lie unconformably below the Cretaceous beds in an uncleaved condition, and the northern boundary of the two formations is a fault-plane, with downthrow to the south, the rocks to the north consisting of folded and cleaved Cape and Karroo Beds. The southern boundary is an unconformity on folded and cleaved beds of the Cape System, the surface on which the Cretaceous beds rest being a very uneven one. In the extreme west of the Uitenhage-Steytlerville basin Enon Conglomerates and Variegated Marls have been preserved in a fault-pit. Similar occurrences of Enon Conglomerate in fault-pits in older rocks have been described from further west in Baviaans Kloof by SCHWARZ. The average dip of the Enon Beds in the basin is about 20 degrees to the south or south-south-east; the dip decreases southwards, the Variegated Marls dipping generally at about 7 degrees, and the Marine Beds at about 4 degrees in the same direction. There is slight local folding, and the beds are affected by post-Uitenhage faults (see Fig. 35).

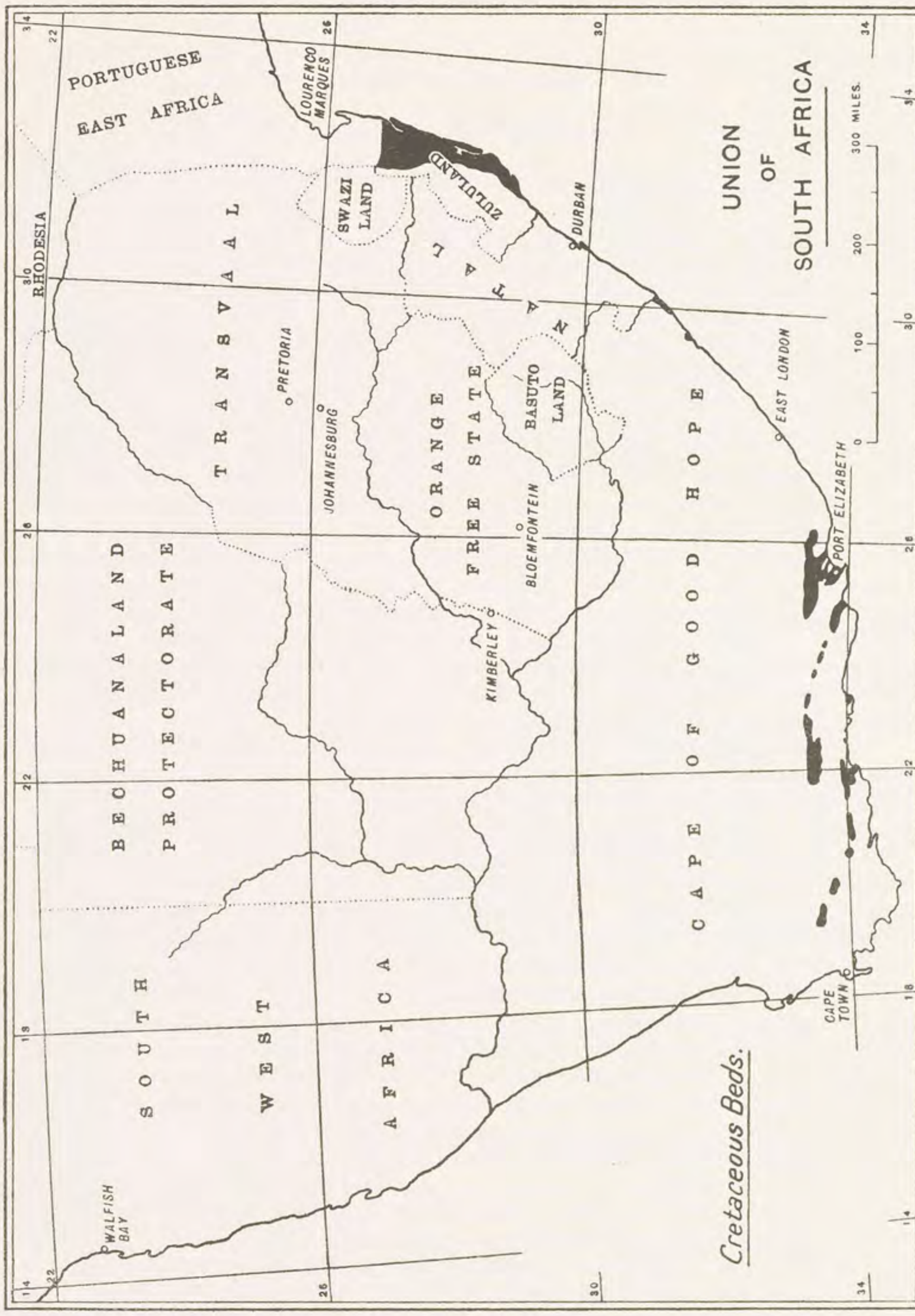

Fig. 34. Outline Map showing the distribution of marine and fluviatile beds of the Cretaceous System.

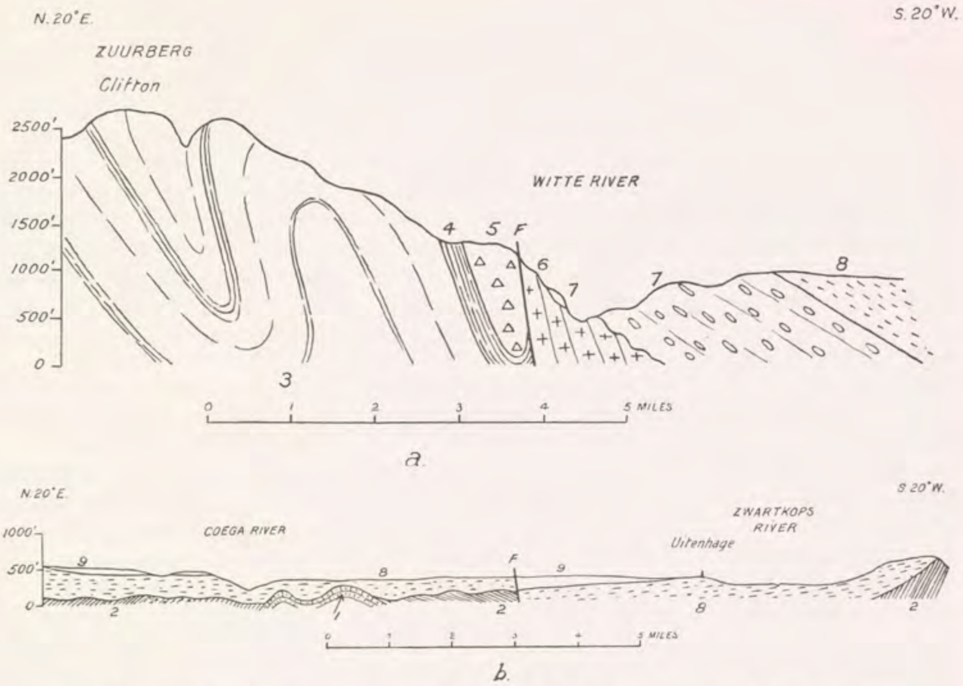

Fig. 35 a and b. Sections across the Uitenhage Basin, south-eastern Cape Province.

1. Table Mountain Sandstone. 2. Bokkeveld Beds. 3. Witteberg Beds. 4. Lower Dwyka Shales. 5. Dwyka Tillite. 6. Pre-Cretaceous (Stormberg?) Volcanics. 7. Enon Conglomerates. 8. Variegated Marls. 9. Sundays River Marine Beds. F. Faults.
Vertical scale **six** times horizontal scale.

In the Gamtoos and Kabeljouws Valleys occur Enon Beds, consisting mainly of thick conglomerates and subsidiary pebble-beds, buff sandstones, and thin pink and white marls with sporadic clays which are sometimes lignitic. The northern boundary of the area is a curved fault-plane, the conglomerates dipping towards the fault plane. The southern boundary is an unconformable one, the beds lying on folded pre-Cape and Cape rocks. The only fossils known are plants, the chief species being *Sphenopteris fittoni*, *Cladophlebis browniana*, *Pseudoctenis rubidgei*, and *Cycadolepis jenkinsiana*.

In the Divisions of Oudtshoorn and Willowmore a considerable tract of country lying between the Zwartberg and Outeniqua Mountains is occupied by conglomerates and sandstones of this series. The conglomerates closely resemble the typical Enon variety, and are both red and white in colour. The sandstones, which lie above the main mass of the conglomerate, but are intercalated with thick conglomerate bands, are rather soft, not quartzitic, and greenish in colour. Bits of fossil wood and sporadic masses of lignite occur in them; and in the Oudtshoorn basin fragments of *Cladophlebis* and Dinosaurian teeth have been found.

Three small patches occur in the neighbourhood of Knysna. In one of them are marine beds (conglomerates and clays) which have yielded species found in the Uitenhage basin. The other patches consist of conglomerates—sometimes with angular inclusions—sandstones, quartzitic sandstones, and clays with lignite.

An area 50 miles (80 km) lang and up to 15 miles (24 km) in breadth, containing a thickness of over 1000 ft. (305 m) of conglomerates, shales, and sandstones, occurs in the neighbourhood of Mossel Bay. The clays contain fossil plants, the speciesof which are generally the same as those found in the "Wood Beds" of the Uitenhage basin, but the well preserved *Osmundites Kolbei* found near Herbertsdale is unknown in the East. Isolated outliers of Uitenhage Beds also occur at Heidelberg, Swellendam, Ashton, and Worcester. The northern boundary of the Cretaceous in the country from Mossel Bay to Worcester is a fault-plane with a throw to the south. The general nature of the beds in each of the areas is similar; but there is much minor variation, and the shales, sandstones, and conglomerates are intercalated with one another, indicating continual and varying changes during the time of deposition. The beds at Heidelberg have yielded *Cyzicus anomala*, *Cypris*, *Unio* ?, ganoid scales and the elytron of a beetle.

b) Embotyi Beds.

On the coast of Pondoland, near the Embotyi River, there is a small triangular area of coarse conglomerates, containing numerous boulders of Karroo sandstones, shales, and dolerite, with a few sandy layers. The beds are unfossiliferous. They are bounded on the north by the Egosa fault-scarp; the beds dip at angles up to 15° to the north-east, and are probably more than 1000 ft. (305 m) thick. Almost certainly of terrestrial or fluviatile origin, it is supposed by du Toit that their accumulation took place at the foot of the Egosa fault while the displacement was slowly increasing in magnitude, the debris being swept from the northern side into the depression developing in the south. The coarsest material occurs to the north.

Further to the south along the coast, at the mouth of the Umgazana, a small area of conglomerates alternating with green grits, grey-green sandstones and dark flaggy beds lies unconformably upon Molteno Beds, and dip at twenty degrees in an east-north-easterly direction. These have yielded invertebrate and plant-remains —the former include species common in the Pondoland Senonian, but the plants consist of genera that are not younger than the Neocomian. Among the former are *Pseudomelania sutherlandi* and *Baculites capensis* (?), while among the latter are *Onychiopsis*, *Cladophlebis*, *Nilssonia*, and *Dictyozamites*. The beds occur on the downthrow side of the Umgazana fault.

c) Umzamba Beds.

For a distance of 25 miles (40 km) along the coast of Pondoland there are disconnected strips of clays, sands, pebble-beds, and limestones which have yielded an abundant fauna of Senonian age. A patch of conglomerates and limestone near the Umpenyati River Mouth on the Natal coast has yielded a similar fauna.

The beds rest, in all probability, upon a planed surface of Table Mountain Sandstone and of granite, and have a slight seaward dip. The fauna is an abundant one, but recent collecting has shown that the beds cannot be divided into zones and represent a single horizon. The chief fossils—which are of Campanian (Upper Senonian) age—are *Hemiaster forbesi*, *Trigonarca capensis*, *Nemodon natalensis*, *Trigonia shepstonei*, *T. elegans*, *Neithea quinquecostata*, *Inoceramus expansus*, *Meretrix umzambiensis*, *Protocardia hillana*, *Pseudomelania sutherlandi*, *Turritella bonei*, *Pyropsis africana*, *Hauericeras gardeni*, *Pseudoschloenbachia umbulazi*, *Mortoniceras soutoni*, *Pseudophyllites indra*, *Gaudryceras kayei*, *Baculites capensis*, *Phylloceras woodsi*. The ammonite fauna is a varied one.

d) Need's Camp Beds.

Two small patches of fossiliferous limestone occur at Need's Camp, near East London, at about 1100 feet (335 m) above sea-level, occupying hollows in the pene-plain which is considered to be of early Tertiary age. The one patch yields numerous casts of *Perna* sp., which is different from the Tertiary *Melina* occurring in the Alexandria Beds. The other contains *Coptosoma capense* and a Polyzoan assemblage which is of Upper Cretaceous age, but which does not yield sufficient evidence to decide whether it is Senonian or Danian. The probability is that the fossils are Danian.

Zululand.

Upper Cretaceous rocks underlie much of the sandy littoral of Zululand between the Umfolosi River and the border of Portuguese East Africa, and a considerable number of fossils are known from certain favourable localities. From a study of the Cephalopods two divisions of the Upper Cretaceous are recognised—Albian and Senonian; but the field evidence is as yet too uncertain to prove the existence of an unconformity between the two.

Albian.

Fossils of this age are known from the Manuan Creek and Umsinene River, from the Mkusi River east of Ubombo, and possibly from the Ingwavuma River in the north. The rocks consist of calcareous conglomerates, containing pebbles of the neighbouring older rocks, calcareous sandstones, and limestones. The chief cephalopods hitherto described are *Phylloceras velledae*, *Dipoloceras cristatum* and *D. quadratum*, *Manuaniceras manuanense*, *Inflaticeras prærostratum* and *I. bispinosum*, *Anisoceras* sp., *Turrilites* cf. *gresslyi*, and several forms of *Cymatoceras*, Lamellibranchs (*Exogyra conica*, *Neithea quadricostata*, *Pholadomya vignesi*) and Gasteropods (*Avellana* cf. *incrassata*) also occur.

Senonian.

The Manuan Creek outcrops have also yielded Senonian forms, but the chief deposit of this age occurs at Umkwelane Hill and neighbouring localities on the Umfolosi River. Here the beds, dipping at about 1^0 seawards and resting upon Stormberg basalts, consist of hard shelly limestones and softer buff-coloured sandstones and other softer sandy beds—sometimes with concretionary fossiliferous limestone nodules. The whole thickness here is not greater than 250 feet (76 km). The fauna is very similar to that of Pondoland Senonian, although a large number of different species occur in the two areas. The most important Cephalopods are the large *Parapuzosia haughtoni*, *Pseudoschloenbachia umbulazi*, *Diaceras tissotiaeforme*, *Mortoniceras woodsi*, *Placenticeras subkaffrarium*, two forms of *Nostoceras*, *Diplomoceras? indicum*, *Baculites capensis* and *B. bailyi*. A number of Senonian Lamellibranchs and Gasteropods are found both on the Umfolosi and at the Manuan Creek localities, Bushmanland.

The old valleys in Bushmanland leading to the Orange River are filled in with thick deposits of granite wash and sand. In one of these, at a depth of 112 ft. (34 m) below the present surface, were discovered a tooth and some bones of an Ornithopodous Dinosaur which was named *Kangnasaurus coetzeei*. This is, in all probability, of Cretaceous age and points to the existence of these valleys in Cretaceous times and their subsequent infilling by continental deposits produced under semi-arid conditions. The only other fossils discovered in the well were pieces of wood not well enough preserved for minute study.

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Cape Sheets 1, 2, 4, 9, 28.

10. Volcanic Pipes younger than the Drakensberg Lavas and Karroo Dolerites.

By

P. A. WAGNER.

Between Middle Cretaceous and Recent geological times the plateau tract of South Africa was riddled with volcanic pipes formed by the explosive liberation at the earth's surface of highly compressed magmatic gases. The pipes belong to at least two widely separated periods of igneous activity, namely (a), an earlier during which were drilled a large number of vents that subsequently became filled with kimberlite, melilite or nepheline basalt and fragmentary material derived from them and the rocks pierced by the explosions; and (b), a very much later period during which the Pretoria Salt Pan volcano came into being.

The kimberlite and the melilite and nepheline basalt pipes are, as already indicated, generally regarded as being contemporaneous. They were probably formed in late Cretaceous or very early Tertiary times as a consequence of the uplift which the whole of Southern Africa underwent at that period.

It should be stated that the melilite and nepheline basalt occurrences are found in the peripheral parts of the Plateau tract and also off it, while the kimberlite pipes are confined to its interior. For this there is probably a deep underlying cause.

A) The Kimberlite Pipes.

The kimberlite pipes, famous because some of them carry diamond in workable quantities, have been most carefully studied and may be dealt with first. They are scattered over a vast extent of country. The southernmost occurrences are in the Sutherland and Beaufort divisions of the Cape Province, Lat. S. 32°30′, and the most northerly so far discovered near Mwanza in Tanganyika Territory, Lat. S.2°30′, while longitude E. 16°30′ and Longitude E. 33°30′ define the western and eastern limits respectively of this great igneous province, probably the most extensive on the face of the earth.

The pipes are invariably found to be clustered together in groups. The discovery of one in a new locality may thus be taken as an indication of the presence of others. The most important groups at present known are those of Kimberley, Pretoria, Jagersfontein, Koffyfontein and Postmasburg.

Evidence is accumulating to show that the pipes are without exception connected with narrow dykes of kimberlite. These in many instances are clearly earlier than the pipes proving that they are situated on preexistent lines of fissuring. In other instances it is evident that a number of pipes are aligned along a concealed subterranean fracture.

There are also actual examples of pipes passing downward or laterally into kimberlite dykes. The finest perhaps is that afforded by the celebrated Kimberley Mine at Kimberley which was successfully worked to a depth of 3520 feet (1073 m) before being finally abandoned. The contours of the pipe at the surface and at depths of 845, 1000 and 2160 feet (258, 305 and 658 m) are shown in Fig. 36.

The configuration of the mighty vent between the 800-ft. (244 m) and 1000-ft. (305 m) levels proves that it was formed by the coalescence of at least three distinct pipes. The more easterly of them loses its individuality below the 845-ft. (258 m)

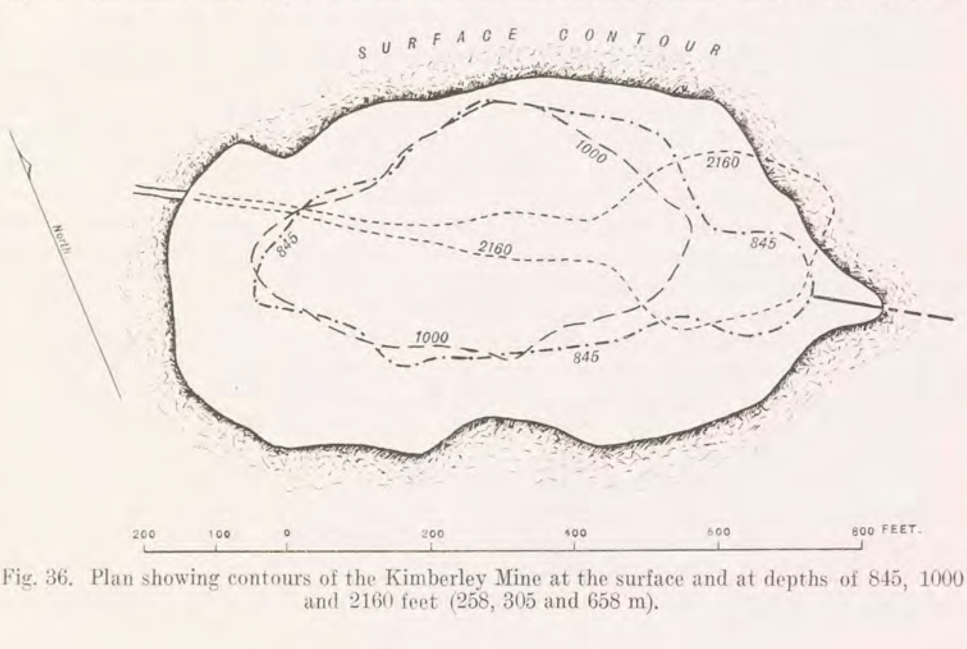

Fig. 36. Plan showing contours of the Kimberley Mine at the surface and at depths of 845, 1000 and 2160 feet (258, 305 and 658 m).

level and at a depth of 1000 ft. (305 m) has either been cut off by, or become part of the main pipe. The western-most pipe persists to a depth of some 2000 feet (610 m) and there passes into a dyke varying in width from 3 to 7 feet (0.91 to 2.13 m) on which a long tunnel was driven on the 2160-ft. (658 m) level. The main pipe persisted far below this and the explosions to which it owes its origin could not have taken place at a less depth than 2400 feet (731 m)[1].

In addition to true pipes there are found along some kimberlite dykes irregular enlargements or swellings of some of which it can be stated with certainty that they were formed far below the surface. They are known as "fissure enlargements" or "blows". Several have been successfully worked (Roberts Victor and Monteleo).

Owing to the fact that the pipes in common with the whole plateau tract have been subject to uninterrupted denudation since they were formed, no vestige remains of the craters by which their orifices must have been surrounded at the surface. As a rule the pipe filling is level with the surrounding surface. Sometimes, however, it is found to protrude slightly or the position of the pipe may be marked by a shallow depression (Premier and Wesselton mines).

The pipes as might be expected, vary considerably in size and shape. The biggest so far discovered is the Premier near Pretoria, which is over half a mile (762 m) in greatest diameter, and has an area of 3560 claims of 31 by 31 feet (9.45 by 9.45 m). Some of the small pipes in the Orange Free State and the northern Cape Province are not more than 100 feet (30.5 m) across.

In ground plan most of the pipes are irregularly oval, but kidney-shaped, dumb-bell shaped and irregularly elongated occurrences are also represented.

Such irregularity is to be expected from the intimate relation existing between pipes and dykes and because, as will be shown, all the larger pipes were formed by a number of separate eruptions.

In elevation every true pipe has the form of a more or less steep-sided funnel, there being, as might be expected, a progressive diminution of area with increase of depth. This shrinkage is, however, not uniform, the walls of most of the pipes so far opened up showing great protuberances and hollows, the latter being attributed to the stoping off from the pipe walls by the magma, as it rose, of masses of rock loosened but not completely detached by the explosions.

As regards posture the pipes are either vertical or steeply inclined.

The Pipe-Filling. The pipes are occupied partly by non-volcanic debris derived from the shattering of the rocks pierced by the explosions, partly by kimberlite and material derived from its trituration, brecciation and decomposition, and at greater depths by solid plugs of that rock. Narrow later dykes of kimberlite cut the pipe filling.

The foreign inclusions range in size from minute microscopic particles to great masses weighing millions of tons. To the latter since the early days of the diamond mines the designation "floating reef" has been applied to distinguish them from the wall rock or "reef" proper.

The smaller inclusions are usually distributed fairly uniformly through the pipe matter. There are found, however, in most pipes great masses or columns of "rubble" composed wholly or in great part of such inclusions.

The inclusions, according to their source of origin, belong to three categories, namely:

a) those derived from the adjacent pipe walls;
b) those brought up from below;
c) those derived from above from strata at one time penetrated by the pipes but long since removed by denudation.

[1] cf. Wagner, P. A. The Diamond Fields of Southern Africa, Johannesburg, 1914, p. 73.

The inclusions belonging to the second and third categories are of particular interest. As examples of the latter may be cited masses of fossiliferous Beaufort sandstone found in the Wesselton Mine near Kimberley; the sandstone having clearly been derived from an horizon in the Karroo succession fully 3000 feet (914 m) above that of the Dwyka shales forming the country rock of the pipe at the present surface. Another is the huge mass of Waterberg sandstone and conglomerate extending right across the Premier Mine near Pretoria, the walls of which are formed of felsite and quartzite belonging to the Pretoria Series.

The inclusions brought up from below include various types of Old Granite, gneiss and schist, and also the remarkable cognate xenoliths of deep-seated holocrystalline ultrabasic rocks to be presently referred to.

A very remarkable feature of the inclusions in the pipe rock is the degree of rounding shown by those composed of hard resistant rocks such as eclogite, granite, quartzite and dolerite. They are not only rounded but in some instances smoothed and polished so as to resemble water-worn boulders. Soft friable rocks such as shale have on the other hand been completely shattered and are scattered through the Blue Ground in the form of innumerable angular fragments.

The same forces that shattered these rocks were evidently responsible for the rounding of the more resistant inclusions which must therefore be attributed to mutual attrition between the rock fragments and between them and the pipe walls during the period of formation of the pipes, and to the violent churning movements that are known to have taken place within the latter. In addition, it is not at all improbable that there was "cup and ball" action on an enormous scale.

Kimberlite and Material derived from it constitutes the pipe rock proper. In opening up a pipe it is usual to meet in descending order with:

1. Yellow Ground representing completely hydrated and oxidised kimberlite, kimberlite tuff and kimberlite breccia. This extends from the surface to a depth of from 35 to 140 feet (10.7 to 42.7 m).
2. Blue Ground, the same rocks in a less altered unoxidised state below the limits of the oxidised zone.
3. Hardebank which is the designation applied to relatively well-preserved kimberlite that does not disintegrate on exposure to the weather.

Yellow Ground is best likened to a dried mud or clay of yellow or yellowish-brown colour.

Blue Ground varies considerably in appearance. As a rule it consists of a serpentinous matrix of slate-blue, bluish-green or bluish-black colour, soft and rather greasy to the touch, through which are scattered with all manner of foreign inclusions, innumerable serpentine pseudomorphs after olivine, glistening plates of phlogopite, and occasional grains of ilmenite, pyrope, enstatite and chrome diopside. Thin sections prove that some blue-ground is merely decomposed kimberlite, other varieties represent altered kimberlite tuff and breccia, and yet others altered injection breccia resulting from the injection of kimberlite into masses of fragmentary material formed by the explosions that drilled the pipes. The inclusions in such injection breccias and those in kimberlite are invariably found to have suffered thermal metamorphism resulting in the development of minerals such as augite, diopside, biotite and garnet.

Kimberlite. As to kimberlite itself it should be stated that there are two main varieties of that rock, namely, a) a mica-poor or basaltic variety allied to melilite basalt, which is especially characteristic of the pipe form of occurrence but is found also in dykes and sills; and b) a mica-rich lamprophyric variety allied to alnöite which in its typical development is found only in dykes, sills and dyke enlargements. The writer at one time held the view that the varieties, which are linked by intermediate types, are restricted in their occurrence to fairly well-defined petrographic provinces, but that view is difficult to sustain in the light of more recent observations.

Thus the blue-ground of the Premier Mine, situated in the heart of what was regarded as a typical province of basaltic kimberlite, contains isolated inclusions of typical micaceous kimberlite, evidently derived from the shattering of an earlier dyke of that rock on traversing the site of the present pipe. Again, the kimberlite of the Voorspoed Mine which was regarded as being of the micaceous variety is really a rather mica-rich variety of basaltic kimberlite, again enclosing lumps of typical micaceous kimberlite. Both varieties of kimberlite, it should be stated, carry diamonds and yield the same types of cognate xenolith.

Basaltic Kimberlite. Owing to the advanced state of decomposition in which this variety of kimberlite is generally found its true nature was long in doubt.

As a rule thin sections show rounded and embayed grains up to ½-inch (1.27 cm) across and smaller idiomorphic crystals of partially serpentinised olivine with irregular plates of phlogopite and grains of ilmenite in a groundmass of secondary serpentine and calcite crowded with minute grains and crystals of perowskite, magnetite and apatite. The olivine is near forsterite in composition. The ilmenite grains are generally rimmed with reaction borders of perowskite. In addition to the minerals named isolated megascopic grains of pyrope, enstatite or bronzite and green diopside are generally in evidence. These and many of the larger olivines are evidently of the nature of cognate xenocrysts derived from the fragmentation of the same deep-seated rocks as the cognate xenoliths to be presently described.

The groundmass of the rock has, as already remarked, generally been completely replaced by serpentine and calcite. In some of the kimberlite which the writer collected on the 2040-ft. (622 m) level of the De Beers Mine and on the 3520-ft. (1073 m) level of the Kimberley Mine the original groundmass is, however, still partially preserved. It consists of minute crystals and grains of a colourless silicate which has been identified provisionally as monticellite. If this identification be correct then basaltic kimberlite may be defined as porphyritic monticellite-olivine-peridotite of basaltic habit.

Micaceous Kimberlite. This, as already stated, is of lamprophyric habit. It consists in its typical development, e. g. in a persistent east and west dyke on the farm Wynandsfontein, Winburg district, Orange Free State, of rounded phenocrysts of olivine and phlogopite lying in a dark fine-textured matrix composed of phlogopite, olivine, apatite, ilmenite, perowskite and chromite, these minerals being accompanied by abundant serpentine and calcite. Occasional megascopic grains of pyrope and diopside are again present but these minerals are rarely seen in handspecimens of the rock. The groundmass contains isolated grains of primary pyrrhotite. The rock is closely allied to alnöite and may be defined as porphyritic mica-peridotite of lamprophyric habit.

In another variety of micaceous kimberlite, exposed near the Crown Diamond Mine in the Kroonstad District of the Orange Free State, the groundmass is rich in small prisms of yellowish augite.

Cognate Xenoliths. In every kimberlite occurrence are found coarsely crystalline nodular xenoliths of ultrabasic composition made up of nearly all possible combinations of the minerals olivine, enstatite or bronzite, diopside, garnet, ilmenite and phlogopite. More rarely cyanite, perowskite, diamond and graphite are present. They have usually the form of flattened ellipsoids and range from a fraction of an inch to 3 feet (2.5—91.4 cm) in longest diameter. The texture is generally hypidiomorphic granular but the rock composing some of the xenoliths clearly shows the effects of dynamic metamorphism.

The commonest rocks represented among the nodules are lherzolite, harzburgite and wehrlite. Particular interest attaches, however, to the eclogite or ariegite nodules, composed essentially of garnet and diopside as quite a number have been found which contain well formed diamond crystals. More rarely graphite is present. The typical eclogites are linked by varieties containing enstatite and olivine with the peridotite xenoliths thus establishing their community of origin. The peridotite xenoliths, it should be stated, also contain isolated diamonds and flakes of graphite.

The origin of these nodular xenoliths has given rise to a great deal of controversy. They are without doubt of the nature of xenoliths brought up from below, but none the less obviously related to kimberlite. The writer has elsewhere[1] put forward the theory that that rock owes its origin to the liquefaction consequent upon relief of pressure or some other cause—of potentially fluid portions of the universal peridotite or sima zone which it is now generally conceded must at great depths underlie the rocks forming the more superficial portion of the earth's crust.

Granting the correctness of this view the simplest explanation of the presence of the xenoliths which are everywhere present is that they are actual specimens of the deepseated peridotites forming this zone and that they became rounded by attrition and solution during their long upward journey. The eclogite represented by the nodules of that rock must be assumed to have formed a continuous zone or schlieren in the peridotite zone or immediately overlying it. It is of interest in this connection to recall that Professor V. M. GOLDSCHMIDT postulates the existence of a universal eclogite zone at great depths in the earth[2].

The Pipes as Products of Successive Eruptions. It has been shown that the blue ground found in different portions of any particular pipe may show marked differences in appearance, properties and diamond content, and the diamonds found in the different varieties of pipe rock may likewise vary considerably in character. It has been proved, moreover, that these differences persist in depth, and appear to be due to variations in the nature of the kimberlite from which the blue ground has been derived. It is thus possible to divide the contents of some of the larger pipes into a number of distinct columns of rock, the contact between which is in many instances quite as sharply defined as that between the blue ground and pipe walls. In view of these facts it appears plausible to infer that each of the columns is the product of a distinct outburst, and that most of the larger pipes have been formed by a number of successive eruptions. This inference is confirmed by the configuration of many of the pipes. The Kimberley pipe, for example, appears to have been formed by the coalescence of at least three distinct chimneys, which in all probability owe their origin to a progressive shifting of the centre of eruption along a WNW—ESE-fissure.

Post Volcanic Effects. The strictly volcanic stage of the eruptions was clearly succeeded in some pipes by a hydrothermal or solfataric stage during which heated magmatic waters ascending through the fragmentary material occupying them gave rise to the formation of minerals such as calcite, zeolites, chrysotile asbestos, mountain cork, pyrite and marcasite[3]. The hydrothermal action also evidently initiated the hydration and serpentinisation of the pipe filling which has since been carried on without interruption by vadose waters, the pipe matter being profoundly altered to depths far below those which atmospheric weathering normally proceeds. Thus even the kimberlite from a depth of 3520 feet (1073 m) in the Kimberley Mine is in a more or less advanced state of serpentinisation.

[1] The Diamond Fields of Southern Africa, Johannesburg, 1914, pp. 117—118.

[2] „Der Stoffwechsel der Erde", Vid.Skrif. I. Mat.-Naturv. Klasse. Kristiania, 1922. No. 11.

[3] Such hydrothermal action was, in the writer's opinion, also responsible for the alteration to their present condition of the remarkable carbonate dykes in the Premier Mine near Pretoria.

A very important consequence of this hydration has been the expansion of the pipe-filling which necessarily took place mainly in an upward direction. It has resulted in many localities in the abrupt upturning of the rocks surrounding pipes at their contact with the yellow ground and in the brecciation and slickensiding of the pipe-filling. The upturning, it should be stated, is a purely superficial phenomenon and is not to be confused with the updoming that preceded the drilling of the Saltpetre Kop and Salt Pan pipes to be presently described. Similar upturning is seen in connection with many kimberlite dykes.

The Diamond and its Origin.

Diamond, when present in the pipe matter, is found well formed crystals, broken crystals and cleavage fragments, a considerable proportion of the last being invariably present. The better class of diamonds are accompanied by bort and by impure stones classed as "rubbish".

Most of the diamonds are tinted. Pure white or "blue-white" stones being confined to certain occurrences. Very pale yellow and pale brown stones predominate. Many of these, however, become practically colourless on being cut. In size the stones range from microscopic crystals to individuals weighing several hundred carats, the biggest ever found being the Cullinan picked up in the Premier Mine. It weighed no less than 3025¾ carats (621 gr), equivalent to 1.37 pounds and was itself only portion of a much larger stone.

The diamond content of the blue ground of even the richest pipes is exceedingly small, ranging from 3 to 30 carats (0.62—6.2 gr) to the hundred loads[1] (511.35 gr), equivalent to from 1/70000 of 1% to 1/7000 of 1%.

Every pipe and every dyke of diamond-bearing kimberlite yields stones characterised by their own peculiarities of crystallisation, colour, lustre, surface markings and the like. It has been established, moreover, that in those pipes where there is evidence of the presence of a number of distinct columns of blue ground formed by successive eruptions each column yields diamonds that are more or less easily distinguished. It is clear, therefore, that every eruption of kimberlite gave rise to stones of distinctive character, which is the best proof that in any particular occurrence the bulk of the diamonds present are normal constituents of kimberlite which must have crystallised from the magma of that rock probably under intratelluric conditions at great depths.

A certain proportion of the diamonds—probably varying in different mines—are, on the other hand, evidently, like many of the larger individuals of olivine, enstatite and pyrope found in kimberlite, of the nature of cognate xenocrysts. Some of them are doubtless attributable to the explosive disruption of bodies of diamond-bearing eclogite belonging to the peridotite zone already referred to, while others may be original constituents of the particular deep-seated peridotites from which the kimberlite magma was derived, that escaped solution and were brought up from below by the magma as inclusions.

B) Melilite and Nepheline Basalt Pipes.

These include three types, namely, a) pipes filled with melilite or nepheline basalt, b) pipes filled partly with one or the other of these rocks and partly with fragmentary material, and c) pipes filled exclusively with the debris of sedimentary and deep-seated igneous rocks of which it can only be surmised from their occurrence

[1] The load, the unit of measurement in the South African diamond mines, represents 16 cubic feet (4.53 cbm) of broken blue ground equivalent to roughly 1600 pounds.

in close proximity to melilite basalt pipes that the magma of that rock supplied the energy for their formation.

a) On the farm Spiegel River, seven miles north-east of Heidelberg in the Cape Province is a volcanic neck occupied by a plug of melilite basalt. It is pear-shaped in transverse section and measures roughly 300 by 200 yards (274,2 by 182,8 m). The pipe pierces conglomerates and sandy beds belonging to the Uitenhage Series[1].

Six miles to the west on the farm Kruis River in tilted lower Cretaceous Beds is a pipe occupied by what has been described[2] as altered kimberlite. Two dykes of the same type of rock are associated with it. The writer, who examined thin sections of these rocks, considers it more probable that we have to do here with altered melilite basalt. This is also rendered probable by the fact that in very similar rock, occurring on the farm Goedvertrouw at the foot of Langebergen near Robertson, Dr. A. W. ROGERS was able to establish the presence of numerous laths of melilite. The last occurrence is of interest in being like the Spiegel River plug definitely off the plateau tract. It is probably related to the Worcester Fault.

East of the Kamiesberg in the western part of Bushmanland on the farms Wolfkraal, Koppieskraal, Onder Gamoep, Zwartheuvel, Bodabeep and Rietfontein is a group of sixteen pipes filled partly with nepheline- and partly with nepheline-melilite basalt[3]. Fifteen of the pipes are confined to a narrow belt of country trending NNW—SSE being evidently aligned on a great subterranean fracture. The pipes range in diameter from 45 to 750 yards (41.1 m to 685.5 m). Some of them are conspicuous objects building hills up to 100 feet (30.5 m) high in an otherwise featureless country. The wall rock in every instance is gneiss[4].

b) The best-known examples of this type are the vents and the semicircular dyke partly surrounding them on the commonage of the village of Sutherland, Cape Province. Some of the pipes are partly filled with ordinary melilite basalt. In others there is present a dark coloured amygdaloidal glass with pseudomorphs of serpentine after olivine and small grains of augite and magnetite. The vesicles are filled with calcite, natrolite, analcite and other zeolites.

On the farm Matjesfontein situated 9 miles (14.5 km) south-east of Sutherland is a pipe partly filled with melilite basalt exhibiting flow structure and partly with a gritty breccia of pale-blue colour containing fragments of granite, Karroo dolerite, quartzite, mica, ilmenite and brown hornblende.

At Silver Dam on the same farm is a breccia-filled pipe about 180 feet (54.8 m) in diameter. The breccia, which resembles blue ground, consists of a serpentinous matrix containing fragments and boulders of quartzite, granite, sandstone and peculiar granulitic rocks composed of monoclinic pyroxene, brown hornblende, brown mica, ilmenite and some felspar. Pieces of hornblende, mica and ilmenite of the same type as those composing the granulite xenoliths are also conspicuous constituents of the breccia and were without doubt derived from the same source as the xenoliths.

The latter and xenocrysts of hornblende, biotite, and ilmenite, which, as already noted, are also found in the Matjesfontein and Sutherland pipes, appear to be typical of this type of melilite basalt occurrence. They are evidently the equivalents of the cognate xenoliths of peridotite and eclogite and the xenocrysts of olivine, bronzite, and other minerals found in the kimberlite pipes. The fact that the granulites

[1] ROGERS, A. W. Rept. Geol. Comm. Cape of Good Hope, 1908, p. 129.

[2] HARGER, H. S. Trans. Geol. Soc. S. Africa, 1922.

[3] ROGERS, A. W. Rept. Geol. Comm. Cape of Good Hope, 1911, pp. 61—72.

[4] Related to these Namaqualand pipes are the melilite basalt occurrences of Lüderitzland, South-West Africa (BEETZ, W. Trans. Geol. Soc. S. Africa, 1924, p. 16), ROGERS, A. W. and DU TOIT, A. L. Rept. Geol. Comm. Cape of Good Hope, 1903, p. 43.

contain a smaller proportion of minerals stable under very high pressures than the eclogites and peridotites suggests that the melilite basalt magma was generated at a less considerable depth than the kimberlite magma.

Another pipe, situated on the farm Tonteldoosfontein a few miles north-east of Silver Dam, is occupied partly by basalt containing nepheline in addition to melilite like some of the Namaqualand pipes.

(c) Of purely breccia-filled pipes the finest example is furnished by Saltpetre Kop, situated in the same area as the pipes with which we have been dealing, about 12 miles (19.3 km) south-east of Sutherland[1]. Saltpetre Kop is a conspicuous hill rising abruptly about 1000 feet (305 m) above the general level of the surrounding country. It is built of a hard siliceous agglomerate occupying a pipe measuring some 3000 by 1700 feet (914 by 518 m). The agglomerate consists of a sandy matrix with angular masses of sandstone, shale and mudstone and fragments of quartzite, granite and schist. Among the smaller constituents of the rock are fragments of felspar, ilmenite, brown mica and hornblende, the last three minerals of the same type as those previously referred to. The breccia is in places strongly impregnated with carbonates of lime and magnesia and with barium sulphate and hydrated oxides of iron. These were evidently deposited from heated magmatic waters during the solfataric stage of the volcanic activity.

A remarkable feature of the Saltpetre Kop vent is the manner in which it has updomed the rocks surrounding it (see Fig. 37). The pipe pierces Beaufort sandstone and shales which are normally nearly horizontal in this region. Around the pipe, however, they have been arched up in a great dome compared by Rogers to a huge solid blister; the dip decreasing regularly in any particular radius from 45^0 and higher near the pipe to 10^0 at a distance of a mile from it. It will be shown that similar updoming of the pierced rocks preceded the drilling of the Pretoria Salt Pan volcano, but here the updoming was followed by subsidence of which there is no evidence at Saltpetre Kop.

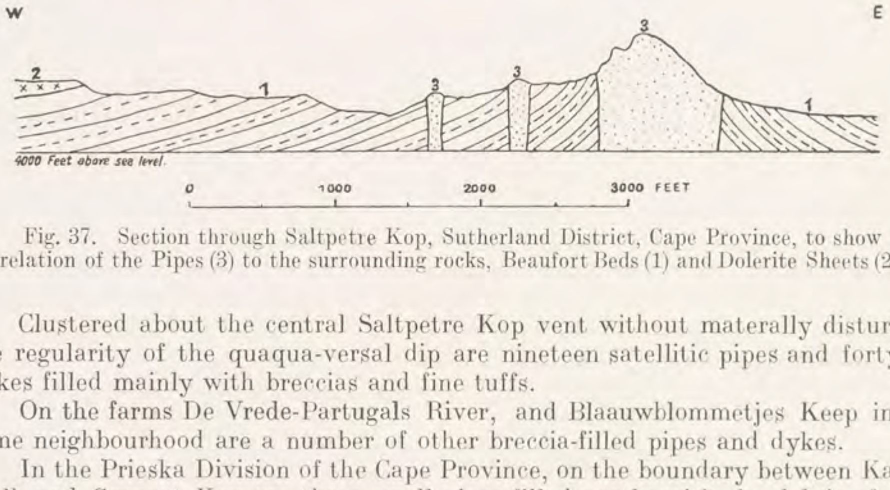

Fig. 37. Section through Saltpetre Kop, Sutherland District, Cape Province, to show relation of the Pipes (3) to the surrounding rocks, Beaufort Beds (1) and Dolerite Sheets (2).

Clustered about the central Saltpetre Kop vent without materally disturbing the regularity of the quaqua-versal dip are nineteen satellitic pipes and forty-six dykes filled mainly with breccias and fine tuffs.

On the farms De Vrede-Partugals River, and Blaauwblommetjes Keep in the same neighbourhood are a number of other breccia-filled pipes and dykes.

In the Prieska Division of the Cape Province, on the boundary between Kaffirs Kolk and Grenaat Kop are three small pipes filled partly with the debris of sedimentary rocks and fragments of igneous rocks allied to kimberlite[2].

A large pipe filled with agglomerate cuts through the Malmesbury slates of the Kobe Valley in the Van Rhynsdorp division of the Cape Province.

[1] Rogers, A. W. and du Toit, A. L. Rept. Geol. Comm. Cape of Good Hope, 1903, p. 57.
[2] du Toit, A. L. Rept. Geol. Comm. Cape of Good Hope, 1908, p. 114.

C) The Pretoria Salt Pan Volcano[1].

Much younger than any of the pipes hitherto dealt with is the Pretoria Salt Pan volcano situated in the Bushveld 25 miles (40 km) north-north-west of Pretoria. The Pan itself is a crateriform depression within a raised rim of circular outline; the flat bottom of the depression, generally covered in its central portion by a shallow sheet of soda-salt brine, lies some 190 feet (58 m) below the general level of the surrounding country which is occupied by coarse red Bushveld Granite.

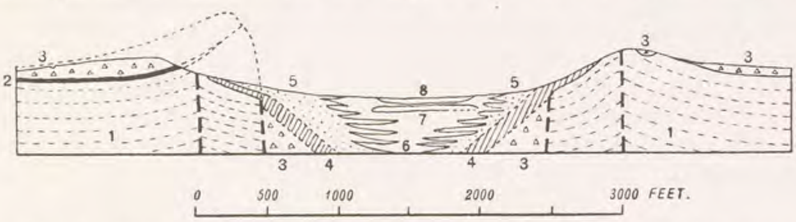

Fig. 38. Section through the Salt Pan Volcano, Pretoria District, Transvaal.

1. Granite. 2. Grit. 3. Granite Breccia. 4. Breccia of Fallen Blocks. 5. Granite Detritus. 6. Laminated Clays with Trona Layers. 7. Gaylussite Layer. 8. Brine.

The diameter of the great hollow measured from rim to rim is roughly 3400 feet (1036 m). The maximum height of the rim above the floor of the Pan is approximately 400 feet (122 m) (see Fig. 38). Though its volcanic nature was long suspected, the true nature of this remarkable isolated Maar was only revealed in the year 1920 by cuttings made at several points in the bounding rim. One of them proves that the rim is a remnant of an originally much larger ring-shaped volcanic cone composed of coarse uncemented breccia, made up largely of angular masses of granite, which here rests on a thickness of 30 feet (9,1 m) of loosely cemented grit itself resting on Red Granite. It should be stated that the grit forms isolated patches and that normally the volcanic breccia rests directly on granite.

Another cutting, by affording evidence of faulting and downwarping, proves that we have to do here not with a simple explosion crater but with a sunken caldera. There is also clear evidence that prior to the drilling of the pipe the surrounding granite was updomed over it. The sequence of events involved in its formation was thus evidently a) Updoming of the granite, b) drilling of the vent, c) subsidence of the interior of the volcano within a ring-shaped fault. The ejectamenta include blocks of foyaite, syenite and norite, and masses of a peculiar dolomitic breccia that possibly represents in a much altered form the volcanic rock responsible for the outburst.

The existing floor of the Pan is formed of a dark sticky mud. This, as already stated, is, as a rule, partially covered with soda-salt brine. It has been explored to a depth of 230 feet (70 m) by means of boreholes. These prove that the central part of the floor is underlain to a depth of 18 feet (5,5 m) by alternating layers of mud and crystallised trona. The mud-trona zone is itself underlain by what is known as the gaylussite layer. This consists of permeable beds made up largely of gaylussite crystals interbedded with and underlain by saline clays and marls. The permeable gaylussite layers are impregnated with clear saturated soda-salt liquor. It is upon this liquor that the soda industry established at the Pan is based.

The writer has shown elsewhere that in so far as the productive portions of the gaylussite layer are concerned this liquor represents a chemical system in equilibrium

[1] cf. WAGNER, P. A. Memoir No. 20, Geological Survey, Union of South Africa, 1922.

and that the system in terms of the Phase Rule is univariant. There is evidence to show that the liquor has been and is being generated by underground water that has forced its way into the caldera deposits from above.

The salts occurring in the caldera were, themselves, evidently introduced at an early stage in its history by volcanic vapours and solutions. The caldera was long occupied by a soda lake which dried up completely during an arid period preceding the present climatic period.

As portion of the original crater ring is still preserved, and it is also clear that the general level of the surrounding country at the time when the outburst occurred could not have been much different from what it now is, the conclusion is inevitable that the Salt Pan volcano must be of comparatively recent origin.

It is the only example so far discovered in the Union of of a vent belonging to this particular period of igneous activity, and may be the southernmost of the East African volcanoes.

11. Cainozoic and later Deposits.

By

S. H. Haughton.

Coastal Deposits.

Resting on a coastal peneplain which slopes seaward at an angle of about 1⁰ is a series of shelly limestones and calcareous sandstones, usually with underlying conglomerates. These were first described by Schwarz as the Alexandria Beds, and a suite of fossils obtained from near Port Elizabeth was considered by Bullen Newton to be of Mio-Pliocene age. Recent work, however, on these very little known deposits goes to show that they are a series of off-shore and in-shore sandy sediments ranging in age from late Eocene to Pliocene, laid down upon a gradually rising plain of marine erosion.

The beds are known from the divisions of Peddie, Bathurst, Alexandria, Port Elizabeth, Uitenhage, Riversdale, Swellendam, Bredasdorp and Caledon along the south coast, and from one or two places along the west coast, especially Alexander Bay, Doorn Bay and Saldanha Bay (see Fig. 39). The highest and presumably oldest beds stand at a height of about 1200 feet (366 m) above present sea-level and the most recent are at or below sea-level. In places they are from 400 to 500 feet (120—150 m) thick. The width of the coastal peneplain is up to 15 miles (24 km). The basal conglomerates do not occur throughout the area; but where they are found they consist of a few feet of large well-rounded pebbles set in a sandy or calcareous matrix, the proportion of pebbles being variable from place to place. The remainder of the series consists of reddish sandstone, calcareous false-bedded consolidated dune-sands and shelly limestones in which the shell-fragments and sand-grains are cemented by secondarily crystallised calcium carbonate; the amount of the latter in these limestones may reach as much as 82 per cent.

Weathering of the limestones yields a red clay; and this, together with calcified and silicified recent wind-blown sands, covers a large part of the Tertiary beds.

The Eocene age of part of the series is based on the occurrence of an *Orthophragmina* associated with other Foraminifera and a *Terebratulina* in a limestone from the Bathurst district. Numerous sharks' teeth, of an approximately Oligocene age, occur in the limestones of Bathurst. The beds from near Port Elizabeth, called Mio-Pliocene by Bullen Newton, contain *Ostrea atherstonei*, *O. redhousensis*, *Melina*

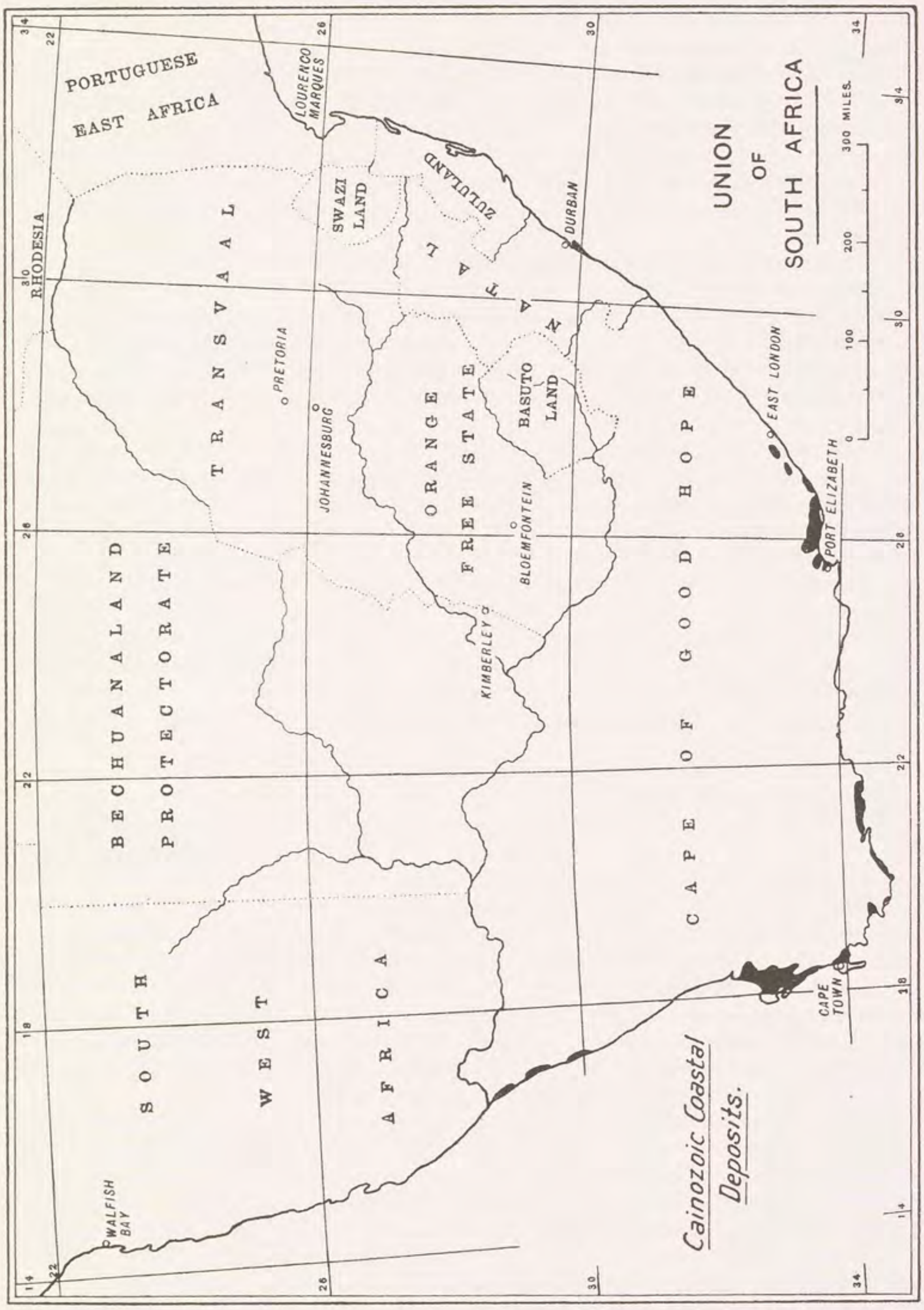

Fig. 39. Outline Map showing the distribution of the Cainozoic Beds.

cf. *gaudichaudi*, *Glycimeris pilosa*, *Chamelea schwarzi*, *C. rogersi*, *Venus verrucosa*, *Tivela baini*, *Cardium edgari*, *Macoma orbicularis*, *Schizodesma spengleri*, *Voluta africana*, *Bullia annulata*, *Melapium patersonae*, *Pirinella stowi* and other forms allied to the existing fauna of the coast.

At Doorn Bay on the west coast impure shelly limestones contain the Miocene forms *Chamelea krigei*, *Donax rogersi*, and *Mytilus tomlini* in addition to species of *Patella* and other gasteropods still living in the seas of the area.

The upper terrace at Alexander Bay, north of Port Nolloth—from which a large number of diamonds have been recovered—also contains *Chamelea krigei* and *Donax rogersi*, in addition to the oyster *Ostrea prismatica*, which is found living to-day in the warm waters of the Natal coast.

To the north-east of Knysna, thick deposits of sand with layers of clay and lignite fill hollows in an old surface. The beds are incoherent in nature and contain fossil wood (*Widdringtonia*) and leaves of *Podocarpus elongata*, *Gonioma kamassi* and *Curtisia faginea* (?); but the beds are trenched to their base by existing rivers and rise to a level of about 1300 ft. (400 m) above present sea-level, resting on the coastal peneplain. They are probably to be correlated with part of the Alexandria Beds.

Raised beaches, varying in height from 10 to 40 ft. (3—12 m) above present sea-level, contain recent shells and one or two species that are as yet unknown as living forms; an interesting point about the raised beaches around Saldanha Bay is that they contain *Ostrea* and other mollusca which no longer exist on the west coast but are to be found to-day in the warmer waters of the south coast.

Mammals and land-shells are abundant in the calcareous sandstones of Saldanha Bay and of the area near Hawston and Stanford— which are consolidated and calcified sand-dunes; the extinct horse *Equus capensis* is known from limestones and sands near Cape Town, and *Elephas zulu* and *Hippopotamus ponderosus* are described from similar deposits on the coast of Natal and Zululand.

The correlation of the various coastal Tertiary deposits is not fully worked out.

Inland Deposits.

Along the southern folded belt from Worcester to Grahamstown and again in East London, Komgha and Kentani there are remnants of a conspicuous peneplain covered with gravel, ferruginous clays, ferricretes, silcretes, and silicified conglomerates or pebble-beds. This peneplain cuts across the pre-Cape, Cape, Karroo, and Uitenhage Beds irrespective of their various amounts of resistance to weathering; and from it rise the various folded mountain-ranges. The plain is gently undulating, having a general seaward slope and a local slope towards the present river valleys by which it is cut; its highest point is about 2600 feet (800 m) above sea-level. In the areas where the silcretes and Tertiary limestones occur close together there is an abrupt step from the one to the other; but where, as in Humansdorp, no limestones occur, the silcrete-covered peneplain slopes evenly to the present coast. The deposits on this surface are never much more than 20 ft. (6.1 m) thick.

The conclusion has been reached that these deposits are contemporaneous with the Alexandria Beds, and that they represent the continental facies of that series of deposits resting upon a river-cut peneplain of the same age as the marine shelf on which the limestones lie. No fossils—with the exception of seeds of *Chara* from Komgha and stems of plants from Fort Grey—are yet known from the silcretes etc.

A lower terrace—well-marked in the valley of the Sundays River—covered mainly with unconsolidated gravels, among which are pebbles of fossiliferous Tertiary limestone, probably marks a pause in the process of uplift which raised the older peneplain to its present position.

Along the courses of the southward-flowing rivers behind the folded ranges, and of the tributaries of the Orange River, are large tracts of alluvium and terraces of river-gravels standing up to 400 ft. (120 m) above the present beds of the rivers and often many miles from them. The geological value of these is not clearly known and comparatively few fossils have been obtained from them. The diamondiferous gravels of the Vaal River form several distinct terraces, from the highest of which near Barkly West the following extinct forms have been made known:—*Mastodon* sp., *Elephas griqua*, *Hippopotamus amphibius* var. *robustus*, *Griquatherium cingulatum*, and *Notochoerus capensis*, as well as the living *Equus zebra* and a *Damaliscus*. From the thick alluvium of the Modder and other rivers the gigantic horn-cores of *Bubalus baini* have been recovered.

In the Kalahari, Bechuanaland, and Griqualand West are extensive superficial deposits of surface quartzites; whilst in many other parts of the inland area are calcareous tufas associated with sand. These, together with the great deposits of sand in the Kalahari and Bushmanland, are probably in part of Tertiary age. The infilling of the valleys in Bushmanland with sand derived from the neighbouring mountains has been in progress since late Cretaceous times. The calcareous tufa deposits of the Campbell Rand near Taungs and Boetsap have been laid down on the edge of the Campbell Rand escarpment, and the limestone contains large sandy patches which have yielded the skull of an ape *Australopithecus africanus* and skulls and limb-bones of a baboon *Papio africanus*. It is possible that both these fossils and the sandy masses which contained them post-date the formation of the main mass of the limestone.

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Map: Cape Sheet 9.

IV. Economic Geology.

By

P. A. Wagner.

The Union of South Africa is rich in minerals of many kinds and ranks at the present time as the world's leading producer of gold, diamonds, osmiridium and corundum. There is also eventually prospect of her becoming the chief producer of platinum and palladium.

The value of the mineral output for the year 1925 amounted to £ 54478307; the principal items being, gold, £ 40767981, diamonds, £8665224, coal, £ 3880442, copper, £ 495717, tin, £ 298973, osmiridium, £ 170995, silver, £ 166842, asbestos, £ 152115, corundum, £ 13229.

The mineral wealth of the Union is concentrated mainly in its east-central portion. Thus the whole of the gold, osmiridium and tin production come from the Transvaal, the entire diamond and asbestos output from Griqualand West and the Transvaal, and all the coal produced from the Transvaal and Natal. It is also in the Transvaal that the chief platinum and iron deposits are situated.

A number of well-defined metallogenetic provinces can be distinguished. The most important is that of the Bushveld Complex and its contact aureole. It contains deposits of gold, platinum, silver, copper, lead, zinc, tin, tungsten, molybdenum, bismuth, nickel, cobalt, arsenic, iron chromium, fluorspar and monazite, and must thus be accounted one of the most remarkable mineral areas on the face of the earth. In dealing with the mineral deposits of the country it might appear most rational to make this and other metallogenetic provinces the basis of our classification. For the purposes of the present publication it will be more convenient, however, to deal with them under the following headings:

A. Precious Metals.
B. Base Metals.
C. Non-Metallic Minerals including Constructional Materials, Coal and Allied Products.

A. Precious Metals.

Gold.

Traversing south-eastern Africa in a north and south direction between longitude E. 26° and E. 32° is a great gold belt which, so far as we know at present, extends from latitude S. 15°30′ to latitude S. 30°30′. It embraces the greater part of the Transvaal and Southern Rhodesia and portions of Natal, Zululand, Bechuanaland and Northern Rhodesia. It is responsible at the present time for over 55 per cent. of the world's annual gold output. Of the 55 per cent., roughly 93 per cent., equivalent to over 50 per cent. of the world output, is derived from the Union of South Africa with which we are here concerned. In that territory economically important deposits of gold occur in the rocks of the Swaziland, Witwatersrand and Transvaal Systems. At the present time the only occurrences being worked are situated in the Transvaal, and of these the mines of the Witwatersrand account for over 98 per cent. of the total production; the value of the annual output of the Witwatersrand being now over 40 million pounds sterling.

1. The Witwatersrand Goldfields.

On these fields, as is well known, gold occurs as a constituent of very persistent beds of quartzitic conglomerate belonging to the Witwatersrand System of sedimentary rocks which has already been fully dealt with (p. 59). The conglomerate is popular known as "banket", the Dutch name for an almond confection which the weathered rock rather remotely resembles.

It has been pointed out that conglomerates occur on a number of horizons in both the lower and upper divisions of the Witwatersrand System. All these conglomerates, locally referred to as "reefs", are auriferous to a greater or less degree, gold being of very widespread occurrence in the Witwatersrand System. So far, however, only those belonging to the Main Reef zone and certain sectors of the Kimberley Reef zone have proved worthy of exploitation on a big scale. It should be stated, however, that notable amounts of gold have also been won at different localities from conglomerates belonging to the Bird, Livingstone and Government Reef zones (see Fig. 40).

The Conglomerates of the Main Reef Zone.

Much the greater part of the huge output of the Witwatersrand has been derived from the conglomerates of the Main Reef zone. They are being worked over an almost continuous stretch of 70 miles (112 km), at depths ranging from a few feet to over 7400 feet (2255.5 m) in the world's deepest mine, the Village Deep, Limited, situated south of Johannesburg.

As developed on the Central Witwatersrand (see Fig. 41) the Main Reef zone contains three well defined bands of conglomerates interbedded with quartzite and a thin bed of chloritoid slate. The three conglomerate bands in descending order are:

3. the South Reef;
2. the Main Reef Leader;
1. the Main Reef[1].

The reefs strike east and west and dip to the south. The dip at the outcrops is steep, ranging from 60° to 80°, but tends to flatten considerably at depth.

1. The Main Reef. The Main Reef is a big body of low-grade banket up to 12 feet (3.66 m) in thickness which has only proved to be workable in places. The chief characteristics of the "reef" are the uniform average size of its pebbles, consisting mainly of white vein quartz, and showing little or no evidence of grading; the occurrence of lenticles or partings of quartzite which divide the reef into two or more bands; and finally the absence of any well-defined foot- or hanging-wall.

Associated with the Main Reef in many of the mines of the Central Witwatersrand and locally replacing it are seams and lenses of banded pyritic quartzite, up to 5 feet (1.52 m) in thickness, generally carrying enough gold to render the rock worth working. The Pyritic Quartzite, as it is termed, is identical in texture and composition with the matrix of the normal gold bearing banket. It evidently originated as a "black sand" deposit.

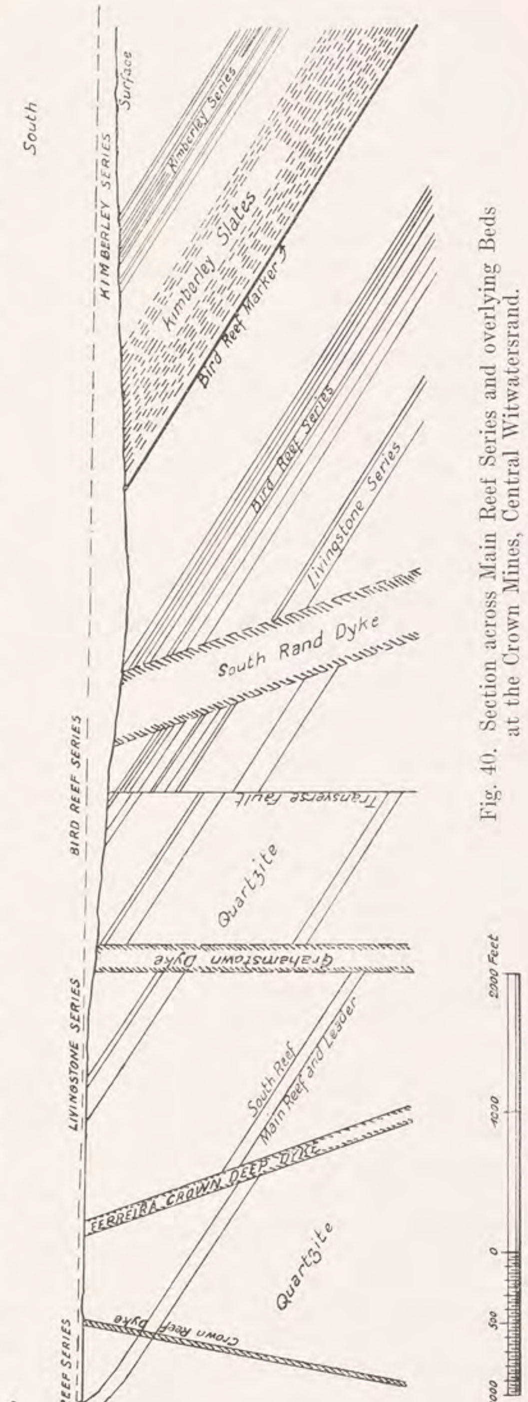

Fig. 40. Section across Main Reef Series and overlying Beds at the Crown Mines, Central Witwatersrand.

[1] The Main Reef is in places underlain at a distance of from 50 to 80 feet by the so-called North Reef, and the South Reef is similarly underlain in places by what is known as the Middle Reef. Neither has any economic significance.

2. The Main Reef Leader, which is the chief gold carrier on the Witwatersrand, averages 2 feet 6 ins. (0.76 m) in thickness. In some areas it lies so close to the Main Reef that they are stoped together. In other areas they are up to 60 feet apart. The "reef" rests directly on a bed of black quartzose chloritoid slate ranging

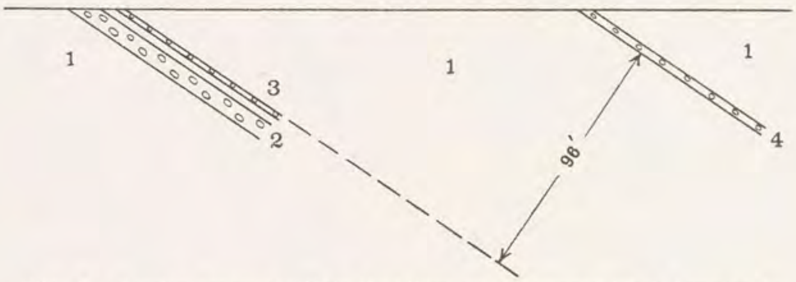

Fig. 41. Section across the Main Reef Zone on the seventh level, Langlaagte Estates Gold Mining Company (Central Witwatersrand).
1. Quartzite. 2. Main Reef. 3. Main Reef Leader. 4. South Reef.

in thickness from 1 inch to 3 feet (0.025 to 0.91 m) (see Fig. 42). This is known as the "Black Bar". In contrast to the Main Reef, the Main Reef Leader shows a considerable range in the size of the pebbles composing it and these afford evidence of grading, so that the largest pebbles often lie directly on the footwall which is always very well defined. Pebbles of bluish-grey, smoky and almost black quartz and white quartz pebbles are present in roughly equal proportions. The conglomerate thus presents a more variegated appearance than that of the Main Reef.

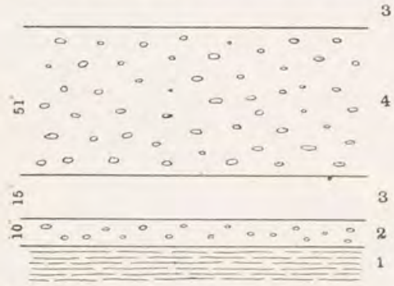

Fig. 42. Section across the Main Reef Zone in No. 2 Shaft, Brakpan Mines. Limited. (Far East Rand).
1. Quartzose Footwall Slate. 2. Footwall Leader. 3. Quartzite Parting. 4. Main Body of Conglomerate.

3. The South Reef is separated from the Main Reef Leader by from 30 to 100 feet (9.1—30.5 m) of quartzite. It resembles the Main Reef in some respects, but alike in the nature of the pebbles composing it and in the presence of a definite footwall parting is more like the Main Reef Leader. It is, as a rule, composite in character, being made up of fairly continuous bands of conglomerate separated by lenses and layers of quartzite. Of the conglomerate bands the lowest or "footwall leader", rarely exceeding 8 inches (20,5 cm) in thickness, carries the major portion of the gold. It is worthy of note that even when this leader becomes so attenuated as to be represented by a single layer of pebbles or merely by a parting plane, as is frequently the case of the West Rand, it may still carry sufficient gold to render it worthy of exploitation[1]. The pebbles of the South Reef are, speaking generally, smaller than those of the Main Reef Leader.

Persistence of the individual "Reefs". It is only in the more central portion of the Witwatersrand goldfield that the Main Reef, Main Reef Leader and South Reef are equally well developed. Proceeding westward the Main Reef Leader gives out[2] at the Vogelstruis Estate, situated 11 miles (17.7 km) west of Johannesburg,

[1] cf. Young, R. B. "The Banket", p. 7.

[2] On the Far West Rand it is represented in places by isolated pebbles, sometimes accompanied by fairly coarse gold.

so that on the Far West Rand only the Main Reef and South Reef are represented; the latter, as previously stated, often by a single line of pebbles or a mere parting plane.

Toward the east, on the other hand, both the Main Reef and the South Reef give out in the neighbourhood of Boksburg, and on the Far East Rand the Main Reef Leader alone remains. It rests directly on a thick bed of slate, the upper portion of which is the equivalent of the "Black Bar" on the Central Rand.

The Far East Rand. It has already been shown that on the Far East Rand, from which the bulk of the Rand gold production now comes, the Witwatersrand beds are disposed in the form of a shallow basin, some 24 miles (38.4 km) across, largely covered by beds of later age, beneath which the suboutcrop of the Main Reef Series has been traced by means of boreholes. Except along the north-western edge of the basin the Witwatersrand beds exhibit low dips. These in the central part of the basin range from 4^0 to 18^0, the average being about 12^0. The thickness of the Main Reef Leader varies from 14 feet (4.27 m) in the central part of the basin to a few inches in the Nigel Mine, situated on its south-eastern edge.

An important point of difference from the Central Rand is that the "reef", speaking generally, does not form a continuous sheet of conglomerate, but is distributed in elongated lenses and patches, with a prevalent NNW—SSE trend, separated by areas of less well developed conglomerate with smaller pebbles or by areas containing no conglomerate at all[1].

In this area the Upper Witwatersrand beds are relatively very little disturbed, wheras on the Central Rand they are very much cut up by faults, particularly of the reverse type, which are often occupied by diabase or epidiorite dykes of considerable thickness.

Petrography of the Banket[2]. Apart from the minor differences, already referred to, the banket of the three main conglomerate horizons presents much the same characters. It is a glass-hard brittle rock composed of ellipsoidal pebbles of vein-quartz, quartzite, and quartz-porphyry, which, with occasional elongated angular and subangular fragments of banded chert and banded ironstone, are set in a fine-grained quartzitic matrix generally fairly rich in pyrite and containing varying amounts of sericite, chlorite and chloritoid. The pebble range in size from that of a pea to that of a hen's egg, the average size being about that of a pigeon's egg. Larger pebbles up to 8 inches (20.3 cm) across are, however, found in places.

The matrix varies in colour from pale-green to blackish-green according as sericite or chlorite predominates. In the oxidised zone, extending to a depth of from 100 to 150 feet (30.5 to 45.7 m), where pyrite is replaced by limonite and other secondary oxides, the colour is reddish or purplish-brown. A considerable number of minerals have been identified in the matrix of the banket. They are divided by YOUNG into allogenic (original) and authigenic constituents. The former include quartz, zircon, chromite, tourmaline, iridosmine and diamond. The authigenic constituents, in addition to pyrite, sericite, chlorite and chloritoid, include quartz, muscovite, anatase, calcite, dolomite, marcasite, carbon, pyrrhotite and other sulphides. Magnetite and ilmenite are conspicuous by their absence which is very remarkable in a rock of this nature. MELLOR[3] and YOUNG assume that both minerals were originally present but that they have been converted into pyrite. The latter constitutes from 1 to 3 per cent. by weight of the banket, and is generally sharply crystallised. Other minerals, more recently identified[4] in the banket, are a strongly radioactive

[1] MELLOR, E. T. "The East Rand", Trans. Geol. Soc. S. Africa, 1915, pp. 57—71.
[2] YOUNG, R. B. "The Banket", London, 1917.
[3] "The Conglomerates of the Witwatersrand"; Trans. I. M. M. London, 1916.
[4] COOPER, R. A. Journ. Chem. Met. Soc. S. Africa, Oct. 1923.

variety of uraninite, a new cobalt nickel arsenide, millerite, and a gold telluride. Monazite is probably also present.

One of the most interesting constituents of the rock is chloritoid in greenish prismatic individuals. This is often abundant, its constant presence in the conglomerates and associated rocks bearing testimony to the advanced metamorphism they have undergone probably mainly as a result of deep burial.

The carbon, to which reference has been made above, occurs in small black opaque nodular grains ranging in diameter from 1 mm downwards, also in minute veinlets with columnar structure, and more rarely in viscous pitch-like condition. It is frequently associated with coarse visible gold, having apparently acted as a precipitant of that metal. YOUNG believes that the carbon has been derived from the inspissation of a liquid hydrocarbon compound.

The Gold and its Origin. The gold content of the "banket" ranges from a trace to many ounces to the ton. The average tenor of the ore milled on the Witwatersrand during 1925 was actually about 6.8 dwts. per short ton, equivalent to 11.7 grammes per metric ton. In some mines on the Central Rand the reefs were markedly enriched at the outcrop, assaying hundreds of ounces to the ton, but such enrichment was purely local.

The gold is practically confined to the matrix of the conglomerate and is one of its rarest constituents, being as a rule so sparsely distributed and so finely divided as to be invisible to the naked eye. Specimens showing "visible", while by no means uncommon, are in point of fact regarded as curiosities. The metal, which is on the whole fairly uniformly distributed, is seen under the microscope to occur in irregular hackly grains, the forms of which resemble those in which gold is found in quartz veins, but are quite unlike those in which it occurs in detrital deposits. More rarely the gold is present in crystals of octahedral habit or in crystal aggregates. It is often intimately associated with pyrite. The gold is alloyed with variable amounts of silver, containing an average of 10 per cent. of that metal.

As to the origin of the gold, this question , until recently one of the most debated in economic geology, may be said to have been finally settled by E. T. MELLOR[1], whose arguments in favour of its being an original constituent of the banket are so convincing that it is not likely that they will ever be seriously challenged. It is necessary, however, on this theory to assume that the gold has undergone solution and reprecipitation in the immediate neighbourhood of where it was originally deposited.

In the Main Reef Leader and South Reefs high gold values are invariably associated with large pebbles, particularly on the footwall, but also in places where the large pebbles do not lie on the footwall and even where they occur as isolated individuals—conclusive proof, as the writer has pointed out elsewhere[2], not only of the primary origin of the gold, but that there cannot have been any appreciable migration of the metal.

The precise mode of deposition of the astonishingly persistent Main Reef Leader and South Reef is still in doubt. MELLOR holds the view that the deposition of these conglomerates was a practically continuous act under deltaic conditions, due to the sudden accession of gravelly material, spread by a broad but comparatively uniform "current", to an area on which for some time previous only the finest sediment had been deposited. Other geologists, while admitting that the original gravels may have been deposited under deltaic conditions, find it necessary to assume that they were subsequently worked over by waves and currents on a subsiding littoral.

[1] Trans. I. M. M. London, 1916, pp. 226—291.
[2] Proc. Geol. Soc. S. Africa, 1917, p. XX.

Estimates of Future Production. The total amount of gold that will ultimately be produced on the Witwatersrand from the conglomerates of the Main Reef Series has been the subject of much speculation. In the nature of the problem anything approaching accurate forecast is out of the question. Probably the most reliable figures so far published are those given in 1914 by the Government Mining Engineer in evidence before the Dominions Royal Commission. He estimated the tonnage to be crushed from mines producing at that time to be 587000000 tons, and from mines not then producing at at least the same quantity. From the beginning of 1914 to the end of 1925 there were actually treated 310 030 816 tons which yielded gold to the value of £ 429 223 297. According to this estimate there would thus remain at the present time some 850 000 000 tons which should yield gold to the value of well over £ 1 000 000 000.

The Conglomerates of the Kimberley Reef Zone.

The Kimberley Reef Series is as a rule made up of a large number of conglomerate beds separated by beds of quartzite. The individual conglomerate layers range in thickness from a few inches to many feet. Their pebbles are on the whole bigger than those of the conglomerates of the Main Reef Series. They are sometimes thickly aggregated, sometimes sparsely scattered. The matrix is very similar to that of the conglomerates already described.

On the West Rand certain of the conglomerate beds of the Kimberley Reef zone carry notable amounts of gold uniformly distributed over considerable distances, and are now being worked on a big scale by the Randfontein Central and West Rand Consolidated Gold Mines (see Fig. 43). The former is at present milling over 50 000 tons per month of banket derived from the so-called Lindum and Horesham Reefs which lie respectively 190 (58 m) and 280 feet (85 m) above the upper limit of the Kimberley Shales. The banket averages between 5 and 6 dwts. (7.8—9.3 gr.) of gold per ton.

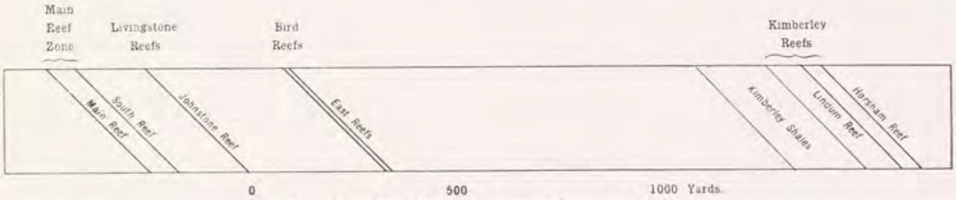

Fig. 43. Section across Main and Kimberley Reef Zones on the Randfontein Estates Gold Mining Company Limited. (Far West Rand).

It is probable that as the reserves of workable ore in the Main Reef Series become depleted the Kimberley Reef Series will play a role of ever-increasing importance as a source of gold production on the Witwatersrand.

The Conglomerates of the Klerksdorp District. Auriferous conglomerates belonging to the Witwatersrand System have been worked at several localities in the Klerksdorp District, notably at Buffelsdoorn. They occur on several horizons but so far these have not been definitely correlated with any of the "reefs" worked on the Witwatersrand. Diamonds are present in considerable numbers in the conglomerate bed originally worked near Klerksdorp by the Klerksdorp Estates Ltd.

2. The Deposits of the Swaziland System.

These deposits, the denudation of which clearly furnished the gold concentrated in the conglomerates of the Witwatersrand System, are as numerous as they are varied. They are also very widely distributed, indeed, gold has been found wherever these ancient rocks appear at the surface.

Barberton District. The most important deposits are those of the Barberton District which have been fully described by A. L. HALL[1]. The deposits are partly in the ancient quartzites and shales of the Moodies Series, and partly in the schists and carbonate rocks of the Jamestown Series, but, as HALL shows, their distribution does not depend upon the nature of the country rock so much as on the proximity of the margins of the great bodies of granite intrusive in the Swaziland System; most of the mines so far worked being situated within the contact aureoles of the Crocodile Poort and De Kaap granite massifs. It should be stated that the intrusion of the granite was accompanied by powerful earth movements, and it is along the fracture and shear planes thereby produced that most of the mineralisation took place. There are also unimportant occurrences in the granites near their contact with the sediments.

Three main types of gold deposits have been worked, namely,

1. replacement or impregnation deposits of more or less regular outline, connected with well-defined fissures, faults or zones of crushing.
2. Contact metasomatic deposits in which gold is accompanied by arsenopyrite.
3. True "reefs" or fissure veins.

In all three types of occurrence the workable ore occurs in shoots which are often extremely rich at the surface, but tend rapidly to become poor at depth.

1. Examples of the first type of deposits are provided by the famous Sheba Mine, the most prolific producer on these fields, which between 1886 and 1918 yielded 952 715 ounces (29 629.45 kg) of gold valued at £ 4 046 876. It consists of four main groups of workings known respectively as the Old or Golden Quarry and the Zwartkopjes, Intombi and Insimbi Mines. They all present much the same features. Gold, in association with pyrite occurring as delicate stringers or in well formed crystals, is found in zones of impregnation or replacement in quartzitic or graphitic slates underlying steeply dipping bars of banded or ferruginous chert. The zones of impregnation are connected with planes of fracture occupied by clay or carbonate matter.

The Main Sheba or Golden Quarry Shoot measured 120 feet (36.6 m) at its widest point and was 300 feet (91 m) long. It conformed roughly to the stratification of the surrounding rocks, and was worked for 1200 feet (366 m) in the direction of the dip. Near the surface it yielded ore averaging 10 ounces (310 gr) of gold to the ton, but values fell off very considerably at depth. An attempt is being made at the present time to reopen this grand old mine, operations being confined to the Intombi and Zwartkopjes sections. Results to date have been disappointing.

2. This type of deposit is illustrated by the Consort and Maid of De Kaap Mines, situated near Noordkaap Siding. In the former the ore occurs, according to HALL, in a series of disconnected lenses in metamorphosed carbonaceous shale, now represented by tourmaline-rich silicified graphitic hornstone. The ore minerals, which are intimately intergrown with the silicates, include, in addition to gold, arsenopyrite, pyrrhotite and pyrite. In the Maid of De Kaap Mine, which presents similar features, there was found in 1925 a patch of ore containing 12 per cent. of gold.

3. Examples of this type of deposit are furnished by the Alpine, Shebang, Durham and Barbrook mines, all of which are on vertical or steeply inclined quartz veins. Such veins have hitherto proved relatively unimportant as a source of gold production.

[1] "The Geology of the Barberton Gold Mining District", Memoir No. 9, Geol. Surv. Union of South Africa, 1918.

Murchison Range[1]. The deposits of the Murchison Range, which from time to time have attracted a good deal of attention, occur in two well defined parallel belts some three or four miles apart corresponding with two conspicuous lines of hills that constitute the central portion of the range. The gold occurrences of the two belts are very similar except in one important particular, and that is, that those of the northern belt almost everywhere contain notable amounts of antimony in the form of stibnite and its oxidation products senarmontite and stibiconite, while that element is absent in the deposits of the southern belt. The northern belt is on this account referred to as the Antimony Belt to distinguish it from the Southern or Spitzkop Belt.

According to MELLOR there are three main types of deposit. They are

1. Lenticular veins, usually composed of coarsely crystalline quartz, or quartz with calcite and other carbonates, showing no schistose structure; the veins, while generally conforming to the foliation of the surrounding rocks, often cutting across it. The most striking characteristic of this class of "reefs" is their rapid and extreme variation in thickness both along the strike and when followed in depth, as well as their want of continuity in both these directions. Gold is often visible to the naked eye and may or may not be accompanied by stibnite in slender prismas or in masses or bunches of considerable size. Pyrite is also generally present.
2. Mineralised Zones in chlorite, talc or quartzose schists. These consist of innumerable lenses and thin sheets of quartz, often exhibiting a schistose structure and usually associated with calcite or dolomite, intimately interleaved with the schists and following their foliation planes. Gold is always accompanied in these deposits by pyrite and in those of the Northern Belt stibnite is also present. The pyrite and stibnite are frequently fractured and sometimes present evidence of having been drawn or rolled out. It is quite clear, therefore, that the mineralisation preceded the general metamorphism of the area. We have here good examples of dynamo-metamorphosed gold deposits.
3. "Black or Burnt Reefs", apparently highly pyritic replacement deposits in banded ferruginous quartz schists, with numerous bands of ferruginous material and sometimes composed entirely of iron oxides. No examples of a deposit of this type carrying stibnite has so far been found.]

All three types of deposit are vertical or steeply inclined. A considerable amount of work has been done on them. Results on the whole have been very disappointing, due partly to the undoubted patchiness of the deposits so far as gold is concerned, and the difficulties of extraction in the case of antimonial ores.

The Letaba Goldfield. In the Letaba Goldfield situated in the "Low Country" some distance north of the Murchison Range, auriferous quartz or quartz-carbonate veins have been worked with indifferent success at the Birthday and Ellerton Mines.

Miscellaneous Deposits. Auriferous gold quartz veins occur in the Swaziland beds at Eersteling, the scene of the first gold discovery in the Transvaal, and other localities to the south and south-east of Pietersburg.

Similar veins in the Old Granite were at one time worked on the Haenertsburg and Woodbush goldfields.

They are also of common occurrence in the Swaziland beds of Natal and Zululand, but so far no really important deposits of this type have been discovered in the territories named.

At Abelskop and Goudplaats in the Harts River Valley, Western Transvaal, gold occurs in quartz stringers in strongly plicated banded ironstones associated with chlorite schist.

At Madibi in the Mafeking division of the Cape Province[2] gold, partly in the form of gold telluride, occurs in association with pyrite and pyrrhotite in quartz

[1] cf. MELLOR, E. T. Ann. Rept. Geol. Surv. Transvaal, 1906, pp. 37—52; and HALL, A. L. "The Geology of the Murchison Range and District"—Memoir No. 6, Geol. Surv. Un. of S. Africa, 1911.

[2] DU TOIT, A. L. Rept. Geol. Comm. Cape of Good Hope, 1905, pp. 230—232.

veins following crush zones in chlorite-biotite-schist and banded ironstone belonging to the Kraaipan Series. Good values were obtained near the surface but the deposits proved very patchy.

At the Denny Dalton and Dickson mines situated in the Vryheid district of Natal beds of auriferous conglomerate belonging to the Lower Pongola Series (Swaziland System) were at one time worked. The Denny Dalton conglomerate contains a good deal of marcasite.

3. Gold Deposits in the Rocks of the Transvaal System.

These include the deposits of the Pilgrims Rest and Sabie Mining Districts which have now for many years ranked next to the Witwatersrand as the most important source of gold in the Union. It will be convenient, however, to begin at the base of the system with the Black Reef.

The Black Reef. This is a thin bed of dark coloured conglomerate which carries profitable amounts of gold in certain localities, notably to the south and south-west of Johannesburg and in the Klerksdorp and Haenertsburg districts. It has been worked at these localities on a fairly big scale, but has invariably proved to be very erratic as to its gold contents, the workable ore occurring in irregular patches. The gold, as on the Witwatersrand, is accompanied by subordinate amounts of iridosmine. At the Machavie Mine, in the Klerksdorp district, the conglomerate is interspersed with nodular bodies of pyrite or marcasite up to ¾ in. (1.9 cm) across, some of which are clearly replacements of pebbles.

Interbedded Quartz Reefs. Interbedded quartz reefs carrying gold occur on a number of horizons in the three members of the Transvaal System in different parts of the Transvaal. They attain their greatest development in

the Pilgrims Rest and Sabie Mining Districts[1],

where some twenty "reefs" of this nature are distributed over a very considerable vertical range, in a tract of rugged country 45 miles (72 km) long and from 7 to 14 miles (11 to 22,5 km) in width.

The highest occur in the Pretoria Series, some 4000 feet (1220 m) above its base, and the lowest in the Black Reef Series. The principal auriferous horizons are shown in their correct positions in the accompanying section (Fig. 44). The reefs all conform strictly to the stratification of the enclosing rocks and dip at from 3^0 to 6^0 to the west.

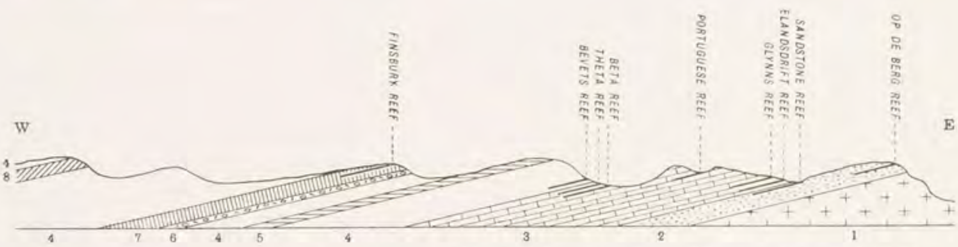

Fig. 44. Diagrammatic Section across the Central Portion of the Pilgrims Rest Goldfield, Transvaal, showing the principal gold horizons.
1. Older Granite. 2. Black Reef Series. 3. Dolomite. 4. Shales and diabase. 5. Timeball Hill Quartzite. 6. Amygdaloidal Andesite. 7. Daspoort Quartzite. 8. Magaliesberg Quartzite.

[1] cf. Hall, A. L. "The Geology of the Pilgrims Rest Gold Mining District", Memoir No. 5, Geol. Surv. Transvaal, 1910; and Wybergh, W. J. "The Economic Geology of Sabie and Pilgrims Rest", Memoir No. 23, Geol. Surv. Un. of S. Africa, 1925.

The most important from the point of view of gold production are the Theta, Portuguese and Glynn's reefs, all of which are in the Dolomite.

The Theta Reef, the most prolific producer in the area, lies 100 feet (30.5 m) below the base of the Pretoria Series, and has been traced for 15 miles (24 km). It ranges in thickness from 4 ins. to 6 feet, (10.1 cm to 1.8 m), the average thickness in the Peach Tree mine being about 22 inches (56 cm). Its gold content varies from a pennyweight to many ounces to the ton; in the richer sections of the Peach Tree Mine it was roughly one ounce (31 gr). The "reef" consists of quartz, generally dull and opaque, heavily charged with big cubical crystals of pyrite, which as a rule have been removed by oxidation, with the result that the reef matter presents the characteristic, cellular, honeycombed appearance. Small amounts of chalcopyrite and its oxidation products are also often present. The reef is frequently bounded above by a layer of soft black manganiferous clay. The gold occurs in a very fine state of division, and is never visible to the naked eye.

The Portuguese Reef. The Portuguese reef, which of late years has become one of the most important in the district, lies some 1200 feet (366 m) below the Theta Reef. It ranges in thickness from 2 ins. to 2 ft. 6 ins. (0.05 to 0.76 m), the average in the Ponieskrans North Mine, where the reef has been extensively worked, being again 22 inches (56 cm).

The Glynn's Reef. The Glynn's Reef lies about 150 feet (46 m) above the base of the Dolomite. It averages 12 inches (0.30 m) in thickness, and consists of dull-looking quartz interlayered with secondary limonite and decomposed dolomite stained with manganese oxides. It is in places very rich and has yielded a gold to the value of nearly £ 3400000.

These Dolomite reefs have apparently been formed by the replacement of thin layers of chert and shaly dolomite by quartz, pyrite and gold, deposited from solutions that worked their way along the bedding planes of the enclosing rock.

Of recent years considerable amounts of gold have been recovered at the Elandsdrift Mine, situated on the farm Elandsdrift, No. 41, from a big elongated flat replacement deposit known as "the Blow" in the Dolomite and shales immediately below the Glynn's Reef horizon. The richer part of the ore-body consists of massive white quartz thickly sprinkled with coarse gold occurring in bright yellow plates, wires and irregular masses, sometimes up to an inch long.

A number of vertical or "cross" reefs cutting across the stratification of the rocks of the Transvaal System have also been worked on the Pilgrims Rest Fields. Examples are the Thelma, Pachonik and Dientje Reefs. They are generally connected with dykes of gabbro or dolerite. The Dientje reefs are of special interest in that gold is here accompanied by bismuthinite, chalcopyrite, bornite and their oxidation products.

The Pilgrims Rest and Sabie fields produce annually gold to the value of some £ 450000, and of recent years have also assumed importance as a source of pyrite.

Other Occurrences. Interbedded quartz reefs, similar to those of the Pilgrims Rest District, occur in the Black Reef Series at Kromdraai, 10 miles (16.09 km) north of Krugersdorp, and in the Pretoria Series near Scheurpoort west of Pretoria, and at Slaaihoek, 10 miles (16.09 km) S.S.E. of Godwan River Station, where a promising little gold mine is being worked.

The Malmani Goldfield[1]. On this field, centred about Ottoshoop in the Western Transvaal, a considerable amount of work has been done on a system of fissure veins intersecting the Dolomite, which here dips at angles ranging from 5^0 to 15^0 to the east-north-east. The veins were discovered in 1875 and production appears to have reached its zenith during the next three or four years. The veins

[1] HUMPHREY, W. A. Rept. Geol. Surv. Transvaal, 1908, pp. 157—160.

have a prevalent north-north-west—south-south-east trend and are either vertical or dip steeply to the west-south-west. They range in thickness from a foot to nearly 100 feet (30.5 m). They consist of quartz or of brecciated dolomite cemented by quartz, or of brecciated quartz cemented by carbonates. Narrow quartz stringers often parallel the main body of the reefs on either side.

The ore minerals are gold, which occurs in nuggety masses, specks and scales, chalcopyrite and bornite and their oxidation products malachite and azurite, pyrite and limonite pseudomorphous after it. The association of gold and copper is characteristic of this field. In some of the veins galena, zincblende and secondary manganese oxides are also present. A number of the veins were rich in gold at the surface, but on the whole they proved very poor and patchy. Mining operations were moreover hampered by the great volumes of water struck at water level—about 150 feet. The field has in consequence acquired a very unfortunate reputation, and is at present lying fallow.

Veins of auriferous quartz in the Pretoria Series were worked at one time on the farms Blaauwbank, No. 104, and Koesterfontein, No. 108, situated in the western part of the Krugersdorp district.

Origin of the Gold Deposits in the Rocks of the Transvaal System. It is probable, as has been suggested by Hall, that the interbedded and normal auriferous veins in the rocks of the Transvaal System are related genetically to the Bushveld Igneous Complex. This is indicated by their distribution; the intimate relation of some of the deposits to dykes connected with the Complex; the occurrence in some of the gold veins of minerals such as bismuthinite, chalcopyrite and galena, which are common in many of the deposits of the Bushveld Igneous Complex; finally by the fact that gold is present in many of the base metal and platinum deposits of the Complex.

4. Alluvial Gold.

Notwithstanding the very wide distribution of primary gold occurrences in the Union South Africa and the stupendous denudation which that territory has undergone since Jurassic times, alluvial gold is surprisingly rare. Indeed, the only really important deposits so far discovered in South Africa are those of the Pilgrims Rest district. Here considerable amounts of the metal were recovered in the seventies of last century from the Pilgrims Creek and Blyde Valley, and the neighbourhood of MacMac and Spitskop, where gold washing on a small scale is still in progress. The total value of the alluvial output to date is estimated at over £ 500000. Part of the gold was of the nature of eluvial gold, and fairly considerable quantities of eluvial gold have also been recovered from the deposits on Mount Anderson in the same district.

Alluvial and eluvial gold, in the form of nuggets and irregular grains, are also found on the Godwan River plateau particularly in the gulleys near the village of Kaapsche Hoop. The Peacock Nugget, weighing 178 ounces (5.44 kg) and named after its finder, was picked up here in 1912.

Alluvial gold has also been worked spasmodically on a small scale at Millwood near Knysna in the Cape Province. The source of the gold is believed to be the Table Mountain Sandstone, exposed near the alluvial workings.

Platinum Metals.

It has been established during the past five years that the Union of South Africa has vast reserves of the platinum metals and there is, as already stated, a prospect of her becoming the chief producer of these metals. The industry is, however, still in its infancy and the output to date has been relatively very small. It has been derived from three sources[1], namely:—

1. The Gold-bearing Conglomerates of the Witwatersrand.
2. The Lode Deposits of the Waterberg District.
3. The Magmatic and Contact Metasomatic Deposits of the Bushveld Igneous Complex.

They will be dealt with in the order given.

1. The Gold-bearing Conglomerates of the Witwatersrand.

1. Platinum metals to the value of over £ 170000 were recovered during 1925 on the Witwatersrand as a by-product of gold mining. They are contained in the "osmiridium" concentrate recovered on the corduroy and blanket tables that have replaced the amalgamation plants formerly employed on the Rand mines. The concentrate is at present the chief source of the world's supply of iridium. It consists of a number of different minerals and contains from 28 to 35 per cent. of iridium, 32 to 39 per cent. of osmium, 9 to 15 per cent. of ruthenium, 6 to 11 per cent. of platinum, and from 0.1 to 0.5 per cent. of rhodium. In addition small amounts of gold are invariably present. The concentrate is shipped to England, and realises an average of £ 28 per ounce.

The total quantity of "osmiridium" contained in the conglomerates of the Witwatersrand System must be enourmous. The available reserves though large, are limited by the fact that it would never pay to recover the concentrate except as a by-product of gold mining. The output will thus necessarily remain proportional to the output of gold on the Witwatersrand, and in particular to that of the mines working the more productive sections of the Far East Rand where the bulk of the "osmiridium" comes from. It will eventually decrease pari passu with the decline of gold production in that area.

2. The Lode Deposits of the Waterberg District[2].

These unique deposits, which have aroused so much interest among geologists, were discovered in July, 1923. They take the form of brecciated quartz lodes occupying faults of post-Karroo age, the platinum having clearly been deposited from vaporous and liquid solutions that circulated along these faults and through the fragmentary material filling them. They are situated in hilly country in the central Transvaal, some eight miles (13 km) WNW of Naboomspruit Station on the Pretoria-Pietersburg railway. A number of lodes have been discovered, but workable bodies of ore were only found in the so-called Main and Branch lodes on the farms Rietfontein, No. 3 and Welgevonden, No. 1772. These were exploited for some time by the Transvaal Platinum, Limited, and have been opened up to a depth of 100 feet (30.5 m) over a distance of 1000 yards (914 m). The workable ore was unfortunately found to be confined to small irregularly patches, and these were so few and far between that it did not pay to look for them below the surface. Operations were finally suspended in August, 1926.

3. The Platinum Deposits of the Bushveld Igneous Complex[3].

These are by far the greatest primary platinum deposits ever discovered, and their true magnitude does not appear as yet to have been properly appreciated (see Fig. 26, Plate III).

[1] WAGNER, P. A. "Occurrence of the Platinum Metals in South Africa." Econ. Geol., March-April-May 1926.

[2] WAGNER, P. A. and TREVOR, T. G. S. African. Journ. Industry Dec. 1923.

[3] WAGNER, P. A. "Notes on the Platinum Deposits of the Bushveld Igneous Complex", Trans. Geol. Soc. S. Africa, 1925, pp. 83—123; and: "Preliminary Report on the Platinum Deposits in the South-Eastern Part of the Rustenburg District, Transvaal", Memoir No. 24, Geol. Surv. Union of S. Africa, 1926.

The Bushveld Complex, as already explained, consists in its outer or lower portion of norite and allied rocks, and in its inner or upper portion of granite, granophyre and felsites. The platinum deposits are contained in the norite which is in the form of a great basin-shaped sheet. All the important occurrences so far discovered are confined to what is known as the Critical or Differentiated Zone in the lower portion of this sheet. They are of four main types, namely:

a) Hortonolite-dunite deposits;
b) Chromitite deposits;
c) Deposits in which platinum is associated with magmatic nickel-copper-iron sulphides;
d) Contact metasomatic deposits in altered dolomite and sheared banded-ironstone immediately underlying platinum-bearing norite and pyroxenite.

In addition to these primary deposits there are also eluvial and alluvial deposits.

a) Hortonolite-dunite Deposits. These take the form of pipe- or parsnip-shaped segregations of hortonolite-dunite in olivine-dunite and diallagite-pegmatite. A considerable number of deposits have been found, but so far only three have been proved to be worthy of exploitation. They are situated in the western part of the Lydenburg district, on the farms Onverwacht, No. 330, Mooihoek, No. 147, and Driekop, No. 170. A fourth occurrence, which is giving promising platinum values, has recently been found on the farm Mooihoek, No. 147, in close proximity to the one above referred to. It is too early, however, to express a definite opinion on it.

The most important occurrence is that on the farm Onverwacht, No. 330, the property of the Transvaal Consolidated Land and Exploration Company, Limited. It measures 60 by 60 feet (18 by 18 m) at the surface, the outcrop being roughly circular. It has been followed to a depth of 300 feet (91 m) and clearly extends far below this. It is becoming gradually smaller in depth, and apparently has the shape of a very elongated parsnip. The platinum content of the dunite varies from one pennyweight (1.55 gr) to 1213 pennyweights (1886 gr) per short ton, the average being between 4 (6.2 gr) and 10 pennyweights (15.5 gr.)

A plant capable of treating 1000 tons per month has been erected, and is now producing about 700 ounces (21.8 kg) of platinum sponge per month. This is sent to England for further refining.

b) Chromitite Deposits. Reference has already been made to the chromitite seams occurring in the lower part of the norite zone. It had been known for years that the chromitite in places carries small amounts of platinum, and fairly high assays were occasionally recorded. Speaking generally, it was found impossible to repeat such assays.

c) and d) Deposits in which platinum is associated with magmatic nickel-copper iron sulphides, and contact metasomatic deposits. Here belong the huge deposits on the Merensky and Main Potgietersrust horizons. The former has been traced at

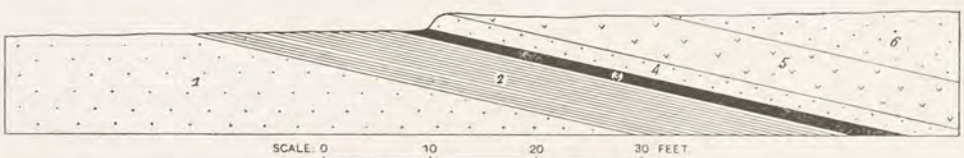

Fig. 45. Section across Merensky Platinum Horizon on the farm Maandagshoek No. 148, Lydenburg District, Transvaal Province.

1. Medium-grained Spotted Norite. 2. Pseudo-porphyritic felspaltic Pyroxenite merging upward into 3. Pseudo-porphyritic pyroxenitic platinum-bearing Norite (Merensky Reef). 4. Spotted anorthositic Norite. 5. Mottled Anorthosite. 6. Coarse-grained spotted Norite.

intervals for a distance of 90 miles (145 km) in the Pietersburg and Lydenburg districts, and for a distance of over 120 miles 193 km) in the Pretoria and Rustenburg districts.

As developed in the Lydenburg district the Merensky "reef", as it is popularly termed, is a remarkably persistent inclined sheet or layer of pseudoporphyritic pyroxenitic diallage-norite carrying small disseminated sulphide specks, or secondary minerals derived from the sulphides (see Fig. 45). The sheet ranges in thickness from 3 to 35 feet (0.9 to 10,7 m) and has an average dip of 14°. Where thin it carries platinum throughout; where thick that mineral is generally concentrated in its uppermost portion. It is underlain and overlain by anorthosite or light-coloured anorthositic norite.

In the Rustenburg district the platinum-bearing layer ranges from 3 to 6 feet (0.91 to 1.82 m) in thickness and is composite in character (see Fig. 46). It consists in its upper portion of light-coloured pseudoporphyritic diallage-norite. This merges downward into pseudoporphyritic pyroxenitic diallage-norite, or felspathic pyroxenite underlain, as a rule, by a thin seam of chromite-rich norite or chromitite, known as the "chrome band". The "reef" proper is everywhere underlain by a sheet of spotted anorthosite. The platinum values are concentrated mainly in the "chromeband" and in the immediately overlying felspathic pyroxenite.

The platinum content of the Merensky "reef" ranges from a pennyweight (1.55 gr) to 246 pennyweights (382 gr) per short ton, the platinum being present partly in the metallic state and partly as a platinum sulph-arsenide. In the Lydenburg district the "reef" has been proved over miles to average between 2 (3.11gr) and 3 pennyweights (4.66 gr) per ton. Shorter stretches carry higher values. In the Rustenburg district the average platinum content appears to be higher than in the Lydenburg district. One 18000-ft. (5486 m) stretch on the farms Klipfontein, No. 538, and Kroondal, No. 177, sampled at intervals of 100 feet (30.5 m) has been found to average 5.6 pennyweights (8.7 gr) over 38 inches (96 cm); the richest sector giving 32 penny-weights (49.8 gr) over 42 inches (1.07 m).

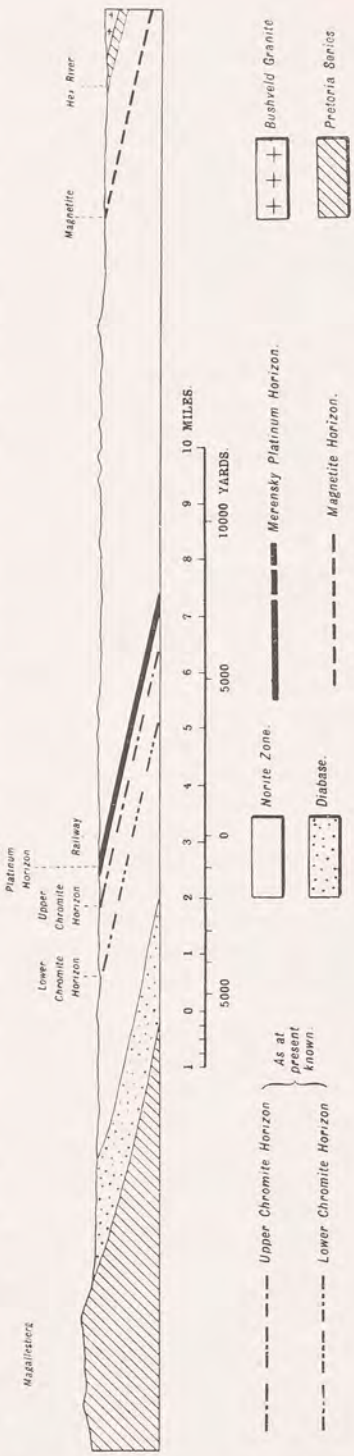

Fig. 46. Section across the Norite Zone of the Bushveld Complex near Rustenburg, showing relative positions of Chromite, Magnetite and Merensky Platinum Horizons.

The Main Potgietersrust Horizon which has been traced for a distance of over 20 miles (32 km) in the portion of the Norite Zone trending north-north-westward from Potgietersrust is probably the equivalent of the Merensky Horizon. It consists speaking generally of a thick sheet of pseudoporphyritic diallage-norite enclosing big lenticular bodies of coarse-grained felspathic bronzitite. Only the latter rock and a coarse-grained hornblende-norite into which it passes locally carry notable amounts of platinum. On Sandsloot, No. 276 the entire thickness of the horizon amounting here to 143 feet (43,58 m) is occupied by these rocks. The uppermost 80 feet (24 m) average over 3 pennyweights (4.66 gr) of platinum per ton.

On the adjoining farms Vaalkop, No. 256 and Zwartfontein, No. 121, the ore horizon has the same characteristics, except that the pseudo-porphyritic norite is only locally developed. The ore horizon is here directly underlain by dolomite or more correctly, calc- and magnesia-silicate rocks derived from dolomite. These rocks for a considerable distance from the igneous contact have suffered impregnation with platinum and sulphides, so that we here have magmatic deposits in juxtaposition with contact metasomatic deposits. In trench No. 1 on Vaalkop, where the composite ore body has been carefully sampled, it averages 7 pennyweights (10.88 gr) over a width, measured horizontally, of 100 feet (30.5 m). On Zwartfontein, No. 121 equally promising values have been obtained. The platinum deposits on Vaalkop and Zwartfontein are among the most important so far opened up in the Bushveld Complex.

Situated a few miles to the south-east is the remarkable contact metasomatic deposit on the farm Tweefontein, No. 1033. Here platinum, in the form of the rare mineral sperrylite, occurs in shear zones in banded ironstone flooring the Bushveld Complex and in sheared intrusions of pegmatite in the banded ironstone. The sperrylite is found in perfect crystals up to 1.7 cm across, that is of a size hitherto unheard of.

Arsenic was here clearly the vehicle that carried the platinum from the norite magma into invaded rocks. It is quite possible therefore that it was also the vehicle responsible for the transfusion of platinum into the silicated dolomite of the Vaalkop-Zwartfontein deposits, in which sperrylite has also been proved to be present.

Available Reserves on the Merensky Horizon. From the nature of the deposits on the Merensky-Potgietersrust Horizon it is to be expected that platinum values of the order of magnitude of those obtained at the surface will be found to persist to the greatest depth ever likely to be reached in mining. This and the figures previously given will make it clear that the available reserves of platinum-bearing rock on these horizons are practically unlimited.

Silver.

The only silver at present being recovered in the Union of South Africa is that contained in the gold bullion produced by the Witwatersrand and other gold mines. The output from this source amounted during 1925 to 934254.26 ounces (29055 kg). The Rand gold, as already stated, contains an average of 10 per cent. of silver, the proportion of silver to gold varying considerably in different parts of the gold field and in one and the same mine. Speaking generally the richer the ore the higher the ratio of gold to silver.

During the period 1922—1925 considerable amounts of silver were produced at the Transvaal Silver Mine, to be presently referred to, the silver being contained in the worklead sent abroad for refining. This mine also produced a good deal of silver before the Anglo-Boer War.

Two other early producers of silver in the Transvaal were the Albert Silver Mine on the farm Roodepoortje No. 149 situated 20 miles (32 km) north-east of Bronkhorstspruit, and the Willows Silver Mine situated on the farm "The Willows" No. 23, 10 miles (16.1 km) east of Pretoria. At the Albert Mine, discovered in 1885, there was worked a well-defined vertical east- and west-replacement lode following a zone of fissuring in granite porphyry. A diabase dyke following the fissured zone forms portion of the lode. The outcrop of the lode was marked by a conspicuous gossan 50 feet (15 m) in width. The lode itself is up to 100 feet (30.5 m) in width. The ore is confined to two fairly definite shoots. The principal ore mineral is argentiferous bornite. This is accompanied by chalcopyrite, tetrahedrite, chalcocite, cuprite, malachite, azurite, native copper and gold. The gangue consists of quartz, specularite and hematite accompanied by subordinate amounts of siderite. The bornite carried up to 1600 ounces (49.76 kg) of silver to the ton, present partly in the metallic state in aborescent forms and partly as the silver sulphide argentite. The deposit was worked to a depth of 230 feet (70 m) and produced fairly considerable quantities of ore averaging 10 per cent. of copper and 40 ounces (1.25 kg) of silver to the ton.

The veins worked at the Willows Silver Mine lie in the shales and diabases separating the Daspoort and Magaliesberg quartzites of the Pretoria Series. They are nearly vertical and the main lode is a contact lode with a hanging-wall of diabase and a footwall of shale. The principal ore mineral was here argentiferous tetrahedrite associated with chalcopyrite, pyrite and secondary copper carbonates. Beautiful azurite crystals were a feature of the oxidised ore. The gangue consists of magnesia-rich siderite containing notable amounts of manganese; at and near the surface it is oxidised to limonite and goethite.

Similar veins outcrop on the farms Boschkop, No. 295 and Oudezwanskraal, N. 537, which are similarly situated with regard to the quartzites of the Pretoria Series. The vein on Oudezwanskraal contains, in addition to the minerals above named, notable amounts of arsenopyrite which affords a connecting link with the tin deposits of the Bushveld Complex.

B. Base Metals.

Antimony.

Antimony in the form of stibnite and its oxidation products, stibiconite and senarmontite, is associated with gold in the northern line of reefs of the Murchison Range in the Leydsdorp District, Transvaal. The ores contain from 4 to 60 per cent. of stibnite. During the Great Ware one of the mines on this line, the Monarch Hill, erected plant for the recovery of the stibnite which was smelted locally and sold for the manufacture of "white metal".

Small amounts of stibnite were also recovered during the same period from a stibnite-quartz lode in the Steynsdorp Division of the Barberton District.

Arsenic.

Small amounts of white arsenic (arsenious oxide) are being recovered as a by-product of gold mining at the Maid of De Kaap and Consort mines in the Barberton District, Transvaal.

White arsenic was also at one time recovered as a by-product at the Stavoren Tin Mine.

On Houtenbek No. 392, situated 65 miles north-east of Pretoria, and the farms to the south-west of it, there are exposed a number of pegmatite veins carrying the rare arsenic mineral leucopyrite (Fe_3As_4) in association with molybdenite.

Bismuth.

Small amounts of very rich bismuth ore, composed mainly of bismutite ochre, were obtained in the nineties of last century from a deposit on the farm Geweerfontein, situated north of the Elands River in the northern part of the Pretoria District. The primary ore consists of arsenopyrite accompanied by subordinate amounts of bismuth glance. It forms isolated replacements in pink felsites. The rich ore was quickly worked out. Attempts made in 1925 to find further ore bodies by electrical prospecting failed.

At the Dientje Mine, situated on the farm Dientje No. 552, 19 miles (30.6 km) north-north-west of Pilgrims Rest in the Transvaal, bismuth is associated with gold and copper in vertical lodes in a big dyke of gabbro, or along the contact of the dyke and the Black Reef sandstone in which it is intrusive. The ore minerals are bismuthinite, chalcopyrite, gold, and pyrite. The gangue consists of lustrous white quartz accompanied by chlorite along the selvages of the veins.

Recently a promising bismuth lode has been opened up on the farm Rhenosterhoek Spruit No 662, situated 14 miles (22.5 km) north-east of the Rooiberg Tin Mine. The ore contains notable amounts of gold and silver.

Chromium.

Stratiform segregations of chromitite or chromite rock have a very wide distribution in the lower part of the Norite Zone of the Bushveld Igneous Complex[1]. The chromite seams can generally be referred to two or more horizons, and such chromite horizons have been traced in the Lydenburg and Rustenburg districts for scores of miles. Immense reserves of the mineral are thus available.

The seams range in thickness from an inch and less to 6 feet (1.8 m). Some of them have been proved to be continuous over stretches of several miles. Others are lenticular and do not persist for any great distance along the strike. The chromitite seams conform strictly to the pseudostratification of the rocks of the Norite Zone. They are in consequence inclined at angles of from 5^0 to 30^0. The chromitite has, as a rule, a peculiar mottled appearance and consists of pseudophenocrysts of bronzit, crowded with minute inclusions of chromite set in a base composed of larger chromite crystals. In addition to the minerals named, subordinate amounts of calcic felspar and diallage are present.

The chromic oxide content of the chromitite ranges from 28 to 49 per cent., the average being somewhere in the neighbourhood of 40 per cent. The biggest and richest deposits are in the Lydenburg District, where the chromite rock is at present being mined on the farms Mooihoek No. 147 and Grootboom No. 186. The ore averages between 42 and 46 per cent. of Cr_2O_3. In the Rustenburg District the average grade is between 35 and 42 per cent. of Cr_3O_2.

A feature of the Bushveld chromite which distinguishes it from the Rhodesian is its richness in ferrous oxide of which it contains from 24 to 28 per cent.

Less important chromite deposits occur in association with the ancient ultrabasic rocks of the Swaziland System in the Northern Transvaal.

Cobalt.

Cobalt was one of the first metals mined after the European occupation of the Transvaal. In the eighties of last century a good deal of rich picked ore was sent to Europe from the old cobalt mine on the farm Kruis River in the Northern part of the Middelburg District, Transvaal. Here cobalt in the form of smaltite and its alteration products, erythrite and transvaalite, occur in narrow replacement veins following the bedding of a dense pink felspathic quartzite, belonging to the Rooiberg Series, immediately below its contact with a thick sheet of gabbro-dolerite[2]. This latter is probably connected with the Norite Zone of the Bushveld Complex exposed a short distance to the north. The veins which parallel the contact dip to the south at 60^0.

[1] Wagner, P. A. "The Chromite of the Bushveld Igneous Complex." South African Journal of Science, 1923, pp. 223—235.

[2] Mellor, E. T. Note on the Field Relations of the Transvaal Cobalt Lodes. Transactions Geol. Soc. S. Africa, 1907, pp. 36—47.

According to MOLENGRAAFF[1] smaltite, associated with molybdenite and chalcopyrite, occurs in narrow lodes in the norite of the Bushveld Complex, on the farm Laatste Drift No. 82, 5 kilometres west of the Kruis River lode.

Workable lode deposits of cobalt were also opened up about 20 years ago on the farm Eenzaamheid, situated 2 miles (3.2 km) south of Balmoral Station on the Pretoria-Delagoa Bay Railway. These lodes, according to MELLOR and BECK[2], are mineralised dykes in altered sedimentary rocks, the dykes being connected with a big neighbouring mass of basic igneous rock. The cobalt minerals are smaltite and cobaltite, with which in one of the lodes a good deal of niccolite is associated. At the outcrop the primary cobalt minerals are replaced by erythrite.

Small amounts of cobalt are also present in some of the mineral deposits in the central part of the Bushveld Igneous Complex.

Copper.

Copper mining has been carried on without interruption in South Africa since 1852, the total value of the output to date being over £ 24000000. Practically the whole of the production has come from the mines of Little Namaqualand and from those on the Messina Copper Belt situated in the Zoutpansberg District of the Transvaal. The very interesting Namaqualand occurrences may first be dealt with.

1. The Copper Region of Little Namaqualand.

This region, occupying a fairly considerable area in the north-west corner of the Cape Province, embraces two distinct areas[3], namely:

a) A northern region characterised by veins containing native copper and copper sulphides in a gangue of quartz, carbonates, felspar, and chlorite. None of them are being worked at the present time. The Kodas and Numees mines, situated in the mountainous country near the Orange River, yielded fair quantities of high-grade ore in the fifties of last century. Transport, however, offered insurmountable difficulties, and they were closed down after being exploited for some years. The former of these mines is said to contain considerable reserves of ore which will doubtless be worked as soon as the area is rendered more accessible by the construction of roads and railways.

b) A southern region embracing an area of about 2000 square miles (5180 km) in the middle of the Division of Namaqualand which contains what are probably the best authenticated examples of copper deposits formed by direct magmatic separation. They take the form of irregular dykes and intrusions of a genetically connected series of rocks, ranging from anorthosite and quartz-rock through mica-diorite and norite to hypersthenite, which contain as primary constituents varying amounts of chalcopyrite which may or may not be accompanied by bornite. In some of the bigger intrusions these minerals form irregular segregations of disseminated and massive sulphide ore. The economically important ore bodies are confined to four main types of ore-bearer[4], namely:

1. Hypersthenite, which forms the intrusion at the Nababeep and Carolusberg mines;
2. Norite, which forms the intrusion at the Tweefontein Mine, and of the Jubilee Mine, near Concordia.

[1] MOLENGRAAFF, G. A. F. The Geology of the Transvaal (Johannesburg 1904). p. 53.

[2] BECK, R. Cobalt Lodes of the Transvaal. Transactions Geol. Soc. S. Africa, 1907, pp. 10—12.

[3] cf. ROGERS, A. W. "The Copper Deposits of Little Namaqualand." Proc. Geol. Soc. S. Africa, 1916, pp. XXI—XXXIV.

[4] This convenient descriptive term was introduced by Dr. ROGERS to cover all the varieties of copper-bearing intrusive rocks.

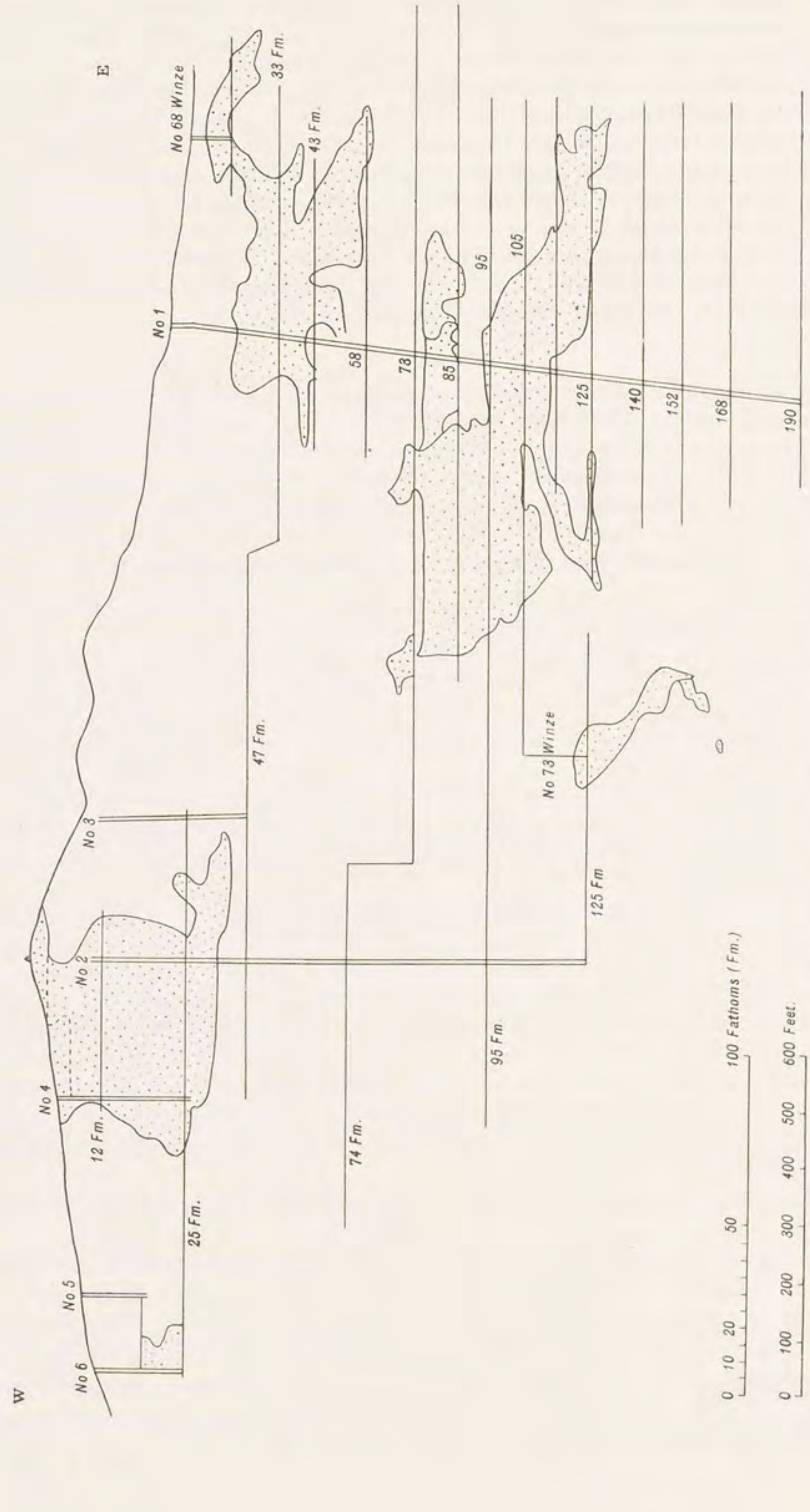

Fig. 47. Projection on a vertical E-W plane of the Tweefontein Copper Mine, Namaqualand, showing disposition and shapes of Ore-bodies.

3. Mica-diorite, the most widely distributed of these rocks which forms the intrusion at the O'okiep Mine.
4. Augite-diorite which forms the ore-bearer of the Springbok Mine.

The country rock is gneissose granite, enclosing bands of sillimanite and sillimanite-garnet-gneiss, which in the area containing the copper mines, is disposed in the form of a great dome. The ore-bodies, as already indicated, are quite irregular in form and, as a rule, irregularly distributed through the ore-bearer in which they occur. The ore bodies are not, as has been stated elsewhere, related to later faults or fissures intersecting the ore-bearers.

The accompanying sections through the Tweefontein Mine, from the unpublished notes of Dr. A. W. ROGERS, give a good idea of the nature of the ore-bodies and of their relation to the ore-bearer (see Fig. 47 and 48). It should be stated that the gneiss in contact with the ore-bearers has in places been impregnated with sulphides which apparently replace the constituents of that rock. Such impregnations are, however, local and quite unimportant.

The mineralogy of the ore occurrences is very simple. Chalcopyrite and bornite are the chief ore minerals. Pyrrhotite is present in some of the deposits, but that mineral and bornite are as elsewhere, mutually exclusive[1]. Magnetite and hematite are generally present and sometimes abundant. Molybdenite is also often seen. The ores carry small amounts of gold which is recovered from the copper produced by electrolytic refining. In the oxidised zone the copper sulphides named are replaced by chalcocite, cuprite, tenorite, malachite, azurite, chrysocolla, and various sulphates, with which is associated the rare mineral cyanotrichite.

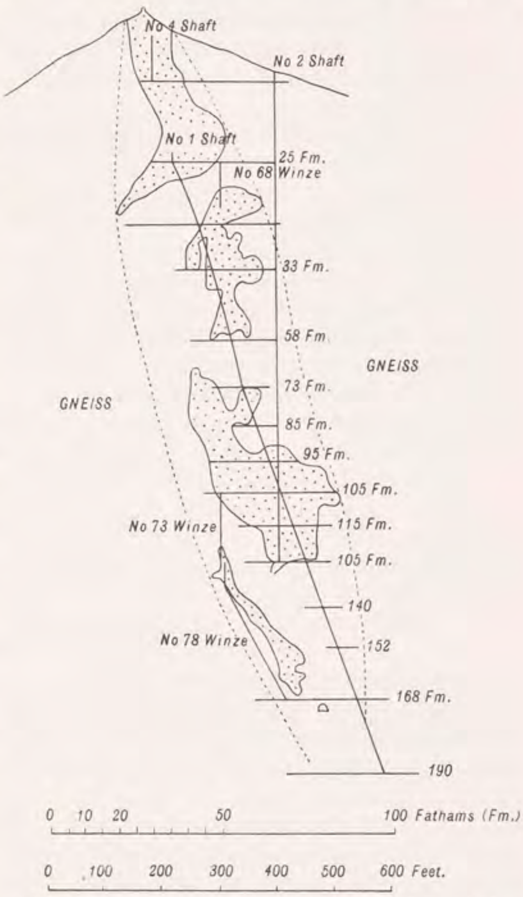

Fig. 48. Projection on a vertical N-S-plane of the Tweefontein Copper Mine, Namaqualand.

Upward of 340 separate intrusions of ore-bearer have been mapped. The more important occurrences may be referred to those in the neighbourhood of:

1. O'okiep, including the O'okiep, O'okiep East, Narrap and Narrap South Mines.
2. Nababeep, in which the Nababeep Mine is the most important.
3. Concordia, including the Tweefontein, Jubilee, Homeeb East and Homeeb West Mines.
4. Carolusberg, inclusing the Carolusberg, Carolusberg East and Koperberg Mines.

[1] TOLMAN C. F. and ROGERS A. F. "A Study of the Magmatic Sulfid Ores", Leland Stanford Junior University Publications 1916.

Fair amounts of ore were also obtained from the Springbok Mine near the village of that name and from the Spektakel Mine on the farm Spektakel north-west of Naries.

By far the most important of these Namaqualand deposits was that worked for many years at the O'okiep Mine. This was a great irregular bulging dyke, 1000 feet (305 m) long and 380 feet (116 m) wide, enclosing big xenoliths of gneissose granite. Vertically the intrusion could only be followed to a depth of 630 feet (192 m) where it apparently comes to an end. It is possible, however, according to Rogers, that it continues, downward as a thin dyke. This deposit was exploited continuously from 1854 to 1915 and produced well over 600000 tons of ore and concentrate averaging 19,5 per cent. of copper. It was for many years the mainstay of the Cape Copper Company.

Two other prolific producers were the Nababeep Mine also belonging to the Cape Copper Company, and the Tweefontein Mine belonging to the Namaqua Copper Company. These three mines have been responsible for much the greater part of the total copper production of Namaqualand, valued at over £ 22000000. At the present time they and a score of lesser mines are worked out. The famous Cape Copper Company has suspended operations and the most promising portion of its holdings is at present being examined by the American Metal Co. Ltd.

The Namaqua Copper Company is still working its East and West Homeeb mines, situated east of Concordia. The ore produced is smelted at Concordia, an average of 230 tons of blister copper being produced per month. In both the mines named development at depth has been very disappointing, and unless new supplies of ore are discovered operations will have to be suspended in the near future.

Altogether the prospects of this grand old mining field are not very hopeful. The great drawback now, as always in the past, are high working costs due to the inaccessibility of the area and its inhospitable, arid nature, which preclude the profitable exploitation of all but fairly rich ore.

2. Messina Copper Belt.

Extending for a distance of 20 miles (32 km) in a general ENE—WSW—direction from the farm Oostenryk No. 1421 to the Limpopo River in the extreme northern part of the Zoutpansberg District of the Transvaal, is a well-defined copper belt. This is honey-combed with ancient workings up to 80 feet (24 m) in depth, and was evidently the scene for hundreds and perhaps thousands of years before the advent of the white man of native copper mining operations. The ore mined, mainly malachite, was smelted on the spot, Ma Singelele Kop, situated east of Messina, having been the site of the principal smelters.

The copper belt ranges in width from 500 to 1000 feet (152 to 305 m), and represents a zone of crushing, faulting and brecciation in the ancient gneissoid and granitic rocks occupying such wide areas of this part of the Transvaal.

The Messina Mine.—The most important deposits are those exploited at the Messina Mine situated on the farm Berkenrode No. 1425, 5 miles (8 km) south of the Limpopo River. The workings of this mine have attained a depth of 2300 feet (701 m). The country rock is composite hornblende-biotite-gneiss with bodies of hornblende-schist and intrusions of a later red granite and still later grey aplite. Special reference must also be made to a persistent steeply inclined dyke of altered dolerite which follows a zone of fissure running roughly along the middle of the copper belt. This dyke, which can be traced for miles, is mineralised in places, and it is believed in some quarters that the solutions that gave rise to the copper deposits emanated from it or from the zone of fissuring which occupies.

The ore-bodies worked are of the nature of irregular discontinuous quartz lodes and big ellipsoidal quartz bodies following well-defined zones of fracture within the main crush zone. The lodes can be referred to two main systems, namely, those striking between North by East and NNE, and those striking approximately NE. They all dip steeply to the ESE or SE.

Most of them would be described as simple lodes. The "K" Lode, however, situated some distance east of the others, is a fine example of a composite lode. It consists of a number of parallel veins of quartz from 4 to 10 feet (1,2 to 3,05 m) in thickness, carrying copper sulphides, which are separated by slabs of country rock up to 15 feet (4.6 m) in thickness; the main quartz veins being linked up by stringers of that mineral. Some very rich ore has recently been opened up in this lode between the 4th and 5th levels.

The most persistent of the lodes has been the North Lode which has been opened up over a length of strike of 1200 feet (366 m) and carried good copper values to a depth of 600 feet (183 m).

The most prolific producer, however, is the much shorter Hanging-Wall Lode. This has carried workable ore from the surface to the greatest depth at which the lodes have so far been opened up, namely 1900 feet (579 m). It is regarded as the main ore-bringer in the western part of the mine, as it invariably gives rise to rich ore-shoots where it intersects the other lodes. Thus the most valuable ore-body so far found in the mine, namely, the "Gringo Shoot", was struck at a depth of 900 feet (274 m) at the intersection of the Hanging-Wall Lode with the normally barren Footwall Lode. A feature of the former is the presence of large and small angular inclusions of gneiss. These show the same type of alteration as the wall rock.

The Middle Lode terminates north-northeastward on the 4th Level of the mine in a big lenticular ore-body.

The mineralogy of the lodes is very simple. The ore minerals are bornite, chalcopyrite and chalcosite. In the upper levels of the mine to a depth of 200 feet (61 m) chalcosite preponderated. Between 200 feet (61 m) and 800 feet (243 m) chalcopyrite is the chief ore mineral, but below 800 feet (243 m) bornite is more abundant. The ore is practically free from gold and silver.

Part of the chalcosite found near the surface was undoubtedly of supergene origin, but that occurring at depth is clearly primary. It is generally in intimate intergrowth with bornite and is still abundant at a depth of 900 feet (274 m). Bornite is slightly later than chalcopyrite, and has developed in part by the replacement of that mineral.

Above water-level the sulphides were represented by malachite, azurite, cuprite, chrysocolla and native copper. A little covellite was found near water-level.

The chief gangue mineral is quartz. This occurs partly as massive coarsely crystalline white quartz, and partly as well-formed quartz crystals arranged in combs and radial aggregates. The quartz is often accompanied by specularite, and the crystals of the mineral are generally dusted with green chlorite. The sulphides are moulded on these chlorite dusted quartz crystals.

According to M. WEBER, who has made a close study of these lodes, quartz is in places accompanied by later pink soda-potash felspar occurring in vugghy aggregates of small crystals. The felspar replaces the quartz but is earlier than the sulphides.

The bulk of the ore occurs in shoots which, as already indicated, are often found as lode intersections or at the intersection of the lodes with cross fractures.

The shoots are up to 150 feet (46 m) in length, and up to 50 feet (15 m) thick, bulging out beyond the normal limits of the lode.

Near the surface the shoots consisted almost exclusively of ore minerals, and averaged over 20 per cent. of copper. At depth even in the richest shoots quartz and other gangue minerals are, without exception, quite as abundant as the sulphides and generally preponderate. There can thus be no question that the lodes are becoming poorer as they are followed downward.

One of the outstanding features of the lodes is the profound alteration which the rocks enclosing them have undergone. They are all bordered by broad alteration mantles. These consist of an inner zone in which prehnite and delessite generally accompanied by laumontite are the predominant alteration products, and an outer zone in which, according to M. WEBER, the place of these minerals is taken by what has been determined by him as zoisite.

Several of the lodes appeared to the writer to be encased in altered aplite. The significance of this aplite and its relation to the lodes remain to be investigated.

Lodes similar to those of the Messina Mine are being worked at the Harper Mine, situated on Vogelnzang, No. 1423, where a rich ore-body has recently been opened up on the 700 — ft. (213 m) level.

The combined output of the Messina and Harper Mines is treated at a central plant situated at the former. This plant produced during 1925 6,446 long tons of copper, valued at £ 320,707. The ore worked averaged 3 per cent. of copper. The reserve in the two mines is sufficient to enable the 1925 output to be maintained for 5 years, and considerable stretches of the copper belt between and on either side of them, also containing ancient workings, remain to be systematically explored.

On the farm Oostenryk, No. 1421, situated on the Copper Belt, some distance W. S. W. of Messina, the Northern Transvaal Copper Company are at present opening up a quartz-copper lode.

Iron.

The Union of South Africa possesses fairly large reserves of high-grade and vast reserves of medium-grade iron ores, the most important deposits being situated in the Transvaal[1]. The principal occurrences may be classified as follows:

1. Deposits formed by magmatic segregation;
2. Replacement deposits connected with igneous rocks;
3. Deposits of sedimentary origin;
4. Deposits of the Lake Superior type.

1. Deposits formed by magmatic segregation.

Here belong the great stratiform segregations of titaniferous magnetite occurring in the upper part of the Norite Zone of the Bushveld Igneous Complex. They are up to 15 feet (4.57 m) in thickness and can be traced for hundreds of miles. They thus contain vast reserves of ore, but owing to their high titania content which ranges from 16 to 19 per cent. there is no prospect of their being utilised in the immediate future. An analysis of a typical specimen of the ore is given in Table 1 (page 187).

There is also an important deposit of titaniferous magnetite of magmatic origin in the Tugela Valley below Middel Drift in Natal. Analyses show from 9.2 to 19.7 per cent. of titanium oxide, and from 42 to 54 per cent. of iron.

2. Replacement deposits connected with igneous rocks.

The most important deposits under this heading is situated on the farm Kromdraai, No. 459, 40 miles (64 km) north-north-east of Pretoria. They are stratiform replacements in a series of conglomerates, grits and tuffs intercalated with the

[1] WAGNER, P. A. "The Iron Deposits of the Union of South Africa". Mem. No. 26. Geological Survey, Union of South Africa. 1928.

felsites of the Rooiberg Series. The dip of the iron deposit conforms to that of these rocks, which is to the south-east at from 10° to 12°. The ore consists mainly of small crystals of specularite. It is very free from phosphorus and sulphur, but on the other hand rather siliceous. Thus a representative sample over a thickness of 11 feet (3.35 m) in the main exposure of what is known as the "blue" ore, occurring at the centre of the deposit, contained 60.5 per cent. of iron and 13.7 per cent. of silica. Another partial analysis of this type of ore is given in Table I. Apart from the "blue" ore, of which only a relatively small tonnage is present, there are moderate reserves of "purple ore" of the same grade and large reserves of more siliceous "red" ore, interspersed with pebbles and fragments of felsite.

Lesser occurrences of specularite ore are widely distributed in the Rooiberg Series, the source of the iron being the Red Granite of the Bushveld Complex.

To the same category as these deposits may be referred the occurrence on Beechwood No. 1405, situated 25 miles (40 km) west-north-west of Nylstroom. It is of the nature of a replacement deposit following a line of fissure in felsite. The ore is hematite containing up to 4.1 per cent. of manganese.

3. Deposits of sedimentary origin.

There are very important deposits of sedimentary iron ores in the Pretoria Series of the Transvaal System and in the Ecca Series of the Karroo System.

Iron Ores of the Pretoria Series[1]. These can be referred to three main horizons, namely:

a) The so-called Magnetic Quartzite;
b) The Clay Band;
c) The Daspoort Horizon.

a) This is an extraordinarily persistent bed of fine-grained arenaceous oolitic ironstone ranging from 7 to 20 feet (2.1 to 6.1 m) in thickness, which can be followed for hundreds of miles. It is conformably interstratified with the quartzites and shales of the Timeball Hill Zone of the Pretoria Series, which, near Pretoria, dip to the north at an average angle of 25 degrees (see Fig. 49). It consists of small oolites made up of alternating concentric layers of magnetite, hematite and chamosite, detrital grains of quartz and crystals of magnetite. The magnetite crystals replace oolites and quartz grains alike, and are evidently due to the recrystallisation of part of the iron oxide present.

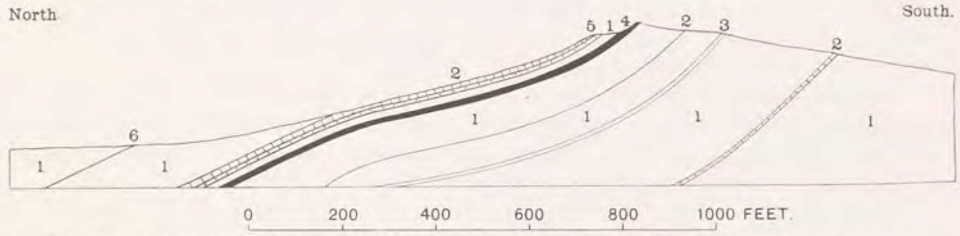

Fig. 49. Section through Timeball Hill Zone on Muckleneuk Hill, south-east of Pretoria.
1. Shale. 2. Quartzite. 3. Ferruginous Quartzite. 4. Magnetic Quartzite.
5. Pisolitic Ironstone. 6. Clay-Band Iron Horizon.

The iron content of the rock ranges from 40.5 to 54 per cent. and the average silica content ranges from 18 to 21 per cent. The ore attains its best average grade on the Pretoria Townlands. The analysis of a representative sample is given in Table 1.

[1] WAGNER, P. A. and STANLEY, G. H. South African Mining Journal, Nos. 1348, 1349, 1351.

b) This is a thin bed of oolitic ironstone ranging from 8 inches to 3 feet (0.2 to 0.9 m) in thickness lying about 180 feet (55 m) above the magnetic quartzite. As developed at depth it consists of oolites of chamosite and magnetite lying in a matrix of siderite and chamosite. Above water-level the siderite and chamosite have been oxidised to limonite and clayey matter and the ore has the character of an argillaceous ironstone, hence its name.

c) This is made up of one or two beds of oolitic or recrystallised oolitic ironstone lying some little distance below the Daspoort Quartzite. It attains its greatest development to the north of Potchefstroom where the main bed, ranging in thickness from 2 to 8 feet (0.6 to 2.4 m), can be traced for miles, and averages between 45 and 50 per cent. of metallic iron.

Iron Ores of the Ecca Series of the Karroo System. Thin seams and attenuated lenses of iron ore are interstratified with the sandstones and shales of the Coal Measure Series (Middle Ecca) of the Karroo System at many localities in Natal and the Transvaal. They are up to 6 feet (1.8 m) in thickness, but the average thickness is between 18 inches and 2 feet (0.45 ad 0.61 m). The ore is variable in character. It may consist of soft earthy limonite and hematite, or of banded siderite, or, as at Prestwick near Dundee, Natal, of black carbonaceous siderite ("Black Band" ore). In some localities these ores have been converted by the contact action of sills of Karroo dolerite into hard compact magnetite (Roodepoort No. 67, Ermelo District, Transvaal).

The ores are for the most part of excellent quality but the reserves are small as iron ore reserves are reckoned. An analysis of an outcrop specimen of the Prestwick ore, above referred to, is given in Table 1 (page 187).

4. Deposits of the Lake Superior type.

Important hematite deposits of the Lake Superior type, that is, secondarily enriched sedimentary ores deposited originally as sideritic cherts, occur in the Crocodile Ward of the Rustenburg District of the Transvaal, and near Postmasburg in Griqualand West. In the firstnamed area[1] the deposits lie athwart the Crocodile River between Latitudes S. 24° 35′ and 24° 40′. They take the form of lenticular or tabular bodies of hematite ore occurring at the base and at the top of a thick zone of banded ironstone. This is referred by some geologists to the base of the Pretoria Series, and by others to the top of the Dolomite. The latter view has much to support it. The individual deposits are up to 1000 yards (914 m) in length and up to 50 feet (15 m) in thickness. The hematite is of exceptional purity (see Table 1), and these are without doubt the most important occurrences of high-grade iron ore so far discovered in South Africa.

The ore clearly owes its origin to a process of secondary concentration whereby the original siliceous layers of certain sections of the zone of rock that is now banded ironstone were replaced by secondary iron oxide giving rise to bodies of massive ore composed of alternating layers of primary and secondary hematite.

Identical and almost equally important deposits of high-grade hematite-ore are developed in Griqualand West in the Klipfontein-Thakweneng range north of Postmasburg. Here again the ore forms lenses in banded ironstone, in part much brecciated. One of the lenses on the farm Klipfontein (M. 24), situated some 12 miles (19 km) south by east of Postmasburg, has a maximum thickness of over 120 feet (36 m). The ore is almost identical with the Crocodile River ore, but contains slightly more phosphorus and sulphur.

The Blink Klip Breccia of Griqualand West. Forming a special phase of this type of deposit are the very extensive occurrences of iron ore in the uppermost

[1] Wagner, P. A. Memoir No. 17, Geological Survey, Union of South Africa.

horizon of the Dolomite Series near Postmasburg in Griqualand West. They represent, according to Dr. A. W. ROGERS[1], a concentration of iron from the originally overlying Pretoria Beds along fissures and circular or elliptical areas of subsidence in the Dolomite. The ore, as typically developed, is a breccia composed of fragments of banded jasper cemented together by hematite, the silica of the jasper fragments being often completely replaced by hematite. There is a considerable development of this type of ore in the Gamagara Ridge west and north west of Postmasburg. The iron content ranges from 38.1 to 67.4 per cent., and very large reserves of high and medium-grade ore are available.

In certain localities the normal fine-grained hematite of the Blink Klip breccia ore is replaced by specularite. This is the case at Blink Klip Kop, 3 miles (4.8 km) north-east of Postmasburg, where there is a fairly big body of pure specular iron ore.

Deposit on Magdala, No. 818, Zoutpansberg District, Transvaal. What are evidently highly metamorphosed deposits of the Lake Superior type were discovered some years ago on Magdala, No. 818, situated 14 miles south-east of Messina; the surrounding rocks being composite gneiss and amphibolite. The ore, which is of great purity, is a massive, coarsely crystalline aggregate of hematite and magnetite. The available reserve, however, is small and the deposits have no economic significance.

Lateritic Surface Ironstone. — The lateritic surface ironstones that have such a wide distribution in South Africa are also always too rich in silica to be of value as a potential source of either iron or alumina.

Banded Ironstones of the Swaziland and Witwatersrand Systems.— The banded ironstones (taconites) of the Swaziland and Witwatersrand Systems have been investigated at several localities, but were found without exception to be too siliceous to be classed as iron ore.

Table 1. Analyses of Iron Ores.

	I.	II.	III.	IV.	V.	VI.
SiO2	0.70	12.10	17,44	5.60	9.15	3.35
TiO_2	19.20	—	Trace	0.20	—	—
Al_2O_3	Trace	—	7.38	5.90	3.77	0.50
Cr_2O_3	0.65	—	—	—	—	—
Fe_2O_3	49.40	83.65	68.11	36.30	72.41	93.50
FeO	28.50	1.90	1.32	34.30	n. d.	2.30
MnO	0.35	—	n. d.	—	—	—
MgO	1.05	—	0,47	0.60	0.76	—
CaO	0.05	—	0.75	0.70	1.70	—
P_2O_5	Trace	Trace	0.39	0.90	0.462	0.05
S	0.10	0.02	0.14	0.04[2]	0.068	nil
CO_2	—	—	—	14.50	—	—
Carbonaceous Matter	—	—	—	—	4.10	—
Moisture				0.15		
Loss on Ignition	0.70	—	4.30	5.10	6.45	0.27
Total	100.65	97.67	100.16	99.71	99.29	99.97
Fe	56.74	60.07	48.60	52.09	50.69	66.23
P	Trace	Trace	0.17	0.02	0.202	0.004
S.	0.10	0.02	0.014	0.39	0.068	nil

I. Titaniferous Magnetite, Rhenosterfontein No. 887, Rustenburg District, Transvaal.
II. Iron Ore, Kromdraai No. 459, Pretoria District.
III. „Magnetic Quartzite" (outcrop specimen), Pretoria Townlands.
IV. Clay-band Ore (at depth of 148 feet), Pretoria Townlands.
V. "Black Band" Iron Ore (outcrop specimen), Prestwick, 16 miles north-east of Dundee, Natal.
VI. Hematite Ore, Buffelshoek No. 151, Crocodile River Iron Fields, Transvaal.

[1] cf. "The Iron Resources of the World". Report of the International Geological Congress, Stockholm, 1911, pp. 1067—1068.
[2] Determined as SO_3.

Lead and Zinc.

Lead.

Deposits of lead and zinc ore have been discovered and worked at a number of localities in the Transvaal and other parts of South Africa. At the present time, however, the output of lead, which during the period 1923—1925 attained considerable proportions, is negligible owing to exhaustion of the more productive deposits.

Two main types of occurrence may be distinguished, namely:

1. Irregular replacements in the Dolomite Series of the Transvaal System;
2. Vein or Lode Deposits.

1. Replacement Deposits.

The most important deposits of this nature are situated in the Marico District of the Transvaal where there is a fairly well-defined Lead belt, 45 miles (72 km) in length, following the uppermost horizons of the dolomite between Klaarstroom No. 55 and Bokkraal No. 300, situated respectively 7 miles (11 km) west of and 30 miles (48 km) south-east of Zeerust[1]. This belt also contains important deposits of zincblende, fluorspar and vanadinite. It is evident therefore that the contact between the dolomite and the impervious overlying shales of the Pretoria Series provided in this area favourable conditions for the circulation of mineral bearing solutions.

It should be stated that within the tract of country under description the rocks of the Dolomite and Pretoria Series dip at low angles to the north or north-east or are disposed in gentle undulations, the dolomite often lying quite flat.

The rocks of both series have throughout the area been intensely metamorphosed as a result of the contact action of the Bushveld Complex (Section 5). The commonest contact mineral in the dolomite is tremolite, occurring in acicular crystals and stellate aggregates of such crystals. Talc is, however, also very common and appears in certain areas to take the place of tremolite. It is certainly not without significance, as will be pointed out later, that the most important lead and zinc deposits occur in the area showing the greatest degree of metamorphism.

The lead deposits present much the same features. They are, as stated, irregular replacements in dolomite or more correctly in soft brownish-black manganese earth which over wide areas has completely replaced the uppermost horizons of the dolomite, this manganese replacement which took place long subsequent to the formation of the lead deposits having clearly proceeded from fissures traversing the dolomite. The lead deposits are as a rule made up of a succession of irregular nodular masses or disseminations of galena or of secondary minerals derived from it. These include cerussite, minium, massicot, pyromorphite and vanadinite. The galena is often accompanied by zincblende. That the galena has developed by the replacement of dolomite is proved by the fact that the original bedding planes of that rock are often clearly discernible on the surfaces of the nodular masses. These range in weight from a few grammes to several tons.

The most important deposit is that of the Doornhoek Mine on Doornhoek No. 32 which has been worked intermittently since the seventies of last century, and is estimated to have yielded altogether some 7000 tons of galena, the latter containing from 5 to 8 (155 to 249 gr) ounces of silver per ton. The galena occurs in the usual nodular masses lying in the soft manganese earth, previously referred to, which here occupies an irregular area lying between two well-defined zones of fissure some

[1] Humphrey, W. A. "The Geology of the South-western Portion of the Marico District". Rep. Geol. Surv. Transvaal 1908, pp. 151—157.

250 yards (228 m), apart and striking approximately north and south. The galena nodules occur in fairly well-defined layers following the original bedding of the replaced dolomite. The manganese earth in places carries notable amounts of cerussite and vanadinite, containing up to 1.15 per cent. of V_2O_5. In the eastern part of the mine, east of the easterly bounding fissure, galena in irregular masses, up to 20 inches (50 cm) across, associated with fluorspar and talc occurs in unreplaced dolomite. The galena occurs along the bedding planes of the dolomite near fissures traversing that rock. This part of the mine gives a good idea of what the main portion of the occurrence was like prior to the replacement of the dolomite by manganese earth.

2. Lode Deposits.

Under this head reference may first be made to the occurrences on the farms Dwarsfontein, No. 143 and Brakfontein, No. 219 situated near Argent Station on the Johannesburg-Witbank railway, some 50 miles (80 km) east of Johannesburg[1]. They are the most productive silver-lead deposits so far discovered in South Africa. They were worked on a big scale between 1889 and 1893, and again between 1922 and 1925 by the Transvaal Silver and Base Metals Company, Ltd. On the farms named norite and pyroxenite belonging to a small offshoot from the Bushveld Complex are intersected by a series of parallel fissure veins striking 50° W. of north. The most important is the so-called Main Lode on Dwarsfontein which can be traced at the surface for over 5000 feet (1524 m). See Fig. 50. It dips south-west at from 45° to 80°. The thickness of the vein varies from 14 feet to nothing, the deposit giving out altogether in places. The primary ore minerals are galena, argentite, native silver, chalcopyrite, pyrite, pyrrhotite, zincblende, tetrahedrite (?) and meneghinite (?). The gangue minerals include siderite (sideroplesite), quartz, chlorite, and dolomite. Argentite occurs as minute microscopic inclusions in the galena which are only rendered visible by etching polished surfaces of the mineral with nitric acid. The galena contains roughly 1 ounce (31.1 gr) of silver to every one per cent. of lead.

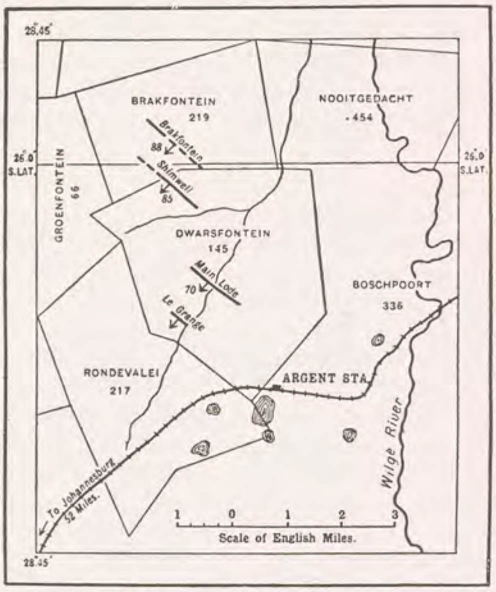

Fig. 50. Map showing principal silver-lead veins near Argent Station, Transvaal Province.

The vein matter is, as a rule, roughly banded parallel to the vein walls, being made up of alternations of galena and siderite-rich bands through which isolated patches of chalcopyrite are scattered. The last-named became increasingly abundant at depth. The workable ore occurs in irregular patches surrounded by barren siderite. The distance between the individual patches was found to increase with increasing depth and at an average depth of about 500 feet (152 m) the vein was no longer workable. The other lodes are similar in character. The ore of the Brakfontein vein is, however, much richer in brown zincblende of which it contains an average of 10 per cent.

There are similar lodes on the farms Spitzkop No. 407 and Hartebeestfontein No. 398 situated 12 miles (19 km) north-east of these occurrences.

[1] WAGNER, P. A. Econ. Geol. 1924, pp. 651—667.

Closely related to these galena-siderite veins is the vein at one time worked at the Edendale Lead Mine situated on the farm of that name 17 miles (27 km) north-east of Pretoria. The ore minerals are galena and zincblende with chalcopyrite appearing at depth as in the Brakfontein vein. The mine has been worked at different times; last between 1904 and 1908 when moderate amounts of both galena and zincblende were produced.

All these veins are clearly related genetically to the Bushveld Igneous Complex.

During the period 1917—1920 notable amounts of galena were recovered from a vein in Waterberg Sandstone on the farm Windhuk situated in the Blaauwberg in the Zoupansberg District of the Transvaal.

At the Balloch Mine, situated 38 miles (61 km) north of Prieska in Griqualand West, there are being worked a series of parallel veins carrying galena accompanied by subordinate amounts of zincblende in a gangue of quartz and ankerite.

Zinc.

Zincblende, as previously stated, occurs in association with galena in many of the deposits of the Marico Lead Belt. In some of these occurrences it is the predominant mineral and two of them have actually been worked as zinc mines. They are the deposits on the farms Witkop No. 288 and Buffelshoek No. 284. They both take the form of remarkable pipes giving rise at the surface to circular outcrops comparable with the zinc "circles" of the Joplin District of the United States.

The Witkop Pipe, which is the more important, measures 170 feet (52 m), from north to south and 160 feet (49 m), from east to west. It is surrounded by an annular zone of tremolite rock which forms a ring-shaped ridge projecting from 2 to 3 feet (61—91 cm) above the surrounding country. This tremolite-rock zone merges outward into less and less tremolitized dolomite, which is here horizontal and quite undisturbed. The maximum alteration of the dolomite thus clearly took place adjacent to the pipe. The deposit is vertical and has the shape of a truncated cone, the diameter increasing gradually with increasing depth down to 280 feet (85 m), the greatest depth reached. The interior of the pipe is occupied for the most part by a coarse breccia composed of blocks of dolomite and shale cemented by calcite, fluorspar and quartz. Zincblende associated with the three gangue minerals named and with subordinate galena and pyrite, follows the outer circumference of the pipe as an annular vein of varying width, which throws off occasional branch veins toward the centre of the occurrence, some of the branch veins opening out into large irregular ore chambers in the breccia already referred to[1].

In the Buffelshoek Pipe talc largely takes the place of tremolite, and zincblende, instead of forming an annular zone, is fairly uniformly distributed through the pipe filling. Fluorspar is abundant, and the pipe thus forms a connecting link with the fluorspar pipe on the farm Oog van Malmani, situated a few miles to the south, to be subsequently referred to.

Manganese.

Manganese ores have a wide distribution in the Union of South Africa, but so far only two really important deposits have been discovered. They are situated north of Postmasburg in Griqualand West and take the form of great sheets, up to 20 feet (6.1 m) thick, formed by the replacement of beds of shale belonging to the basal portion of the Matsap System (see Fig. 51). The main sheet, which dips at a low angle to the west, can be traced at intervals for 40 miles (64 km) in a general

[1] Kupferburger, W. The Fluorspar, Lead and Zinc Deposits of the Western Transvaal. Trans. Geol. Soc. S. Africa, 1927, p. 37.

north and south direction on the western limb of the Maremane anticline[1]. The bulk of the ore is psilomelane, with which subordinate amounts of rhodonite and barytes are in places associated. Sampling indicates that it contains from 38 to 58 per cent. of metallic manganese, from 1.75 to 7 per cent. of silica, from 3.25 to 10.9 per cent. of iron, and from 1 to 19.2 per cent. of alumina. It is practically free from phosphorus and contains from 0.15 to 0.75 per cent. of sulphur.

A conservative estimate shows that some 2,700,000 long tons of ore are actually in sight, 900000 tons of this being in the form of residual cappings. Assuming that the ore only persists to a depth of 100 feet (30.5 m) on the dip, a further 18000000 tons would be indicated. The nearest railhead is Douglas, distant 65 miles (104.6 km) from Postmasburg.

For further details see the forthcoming Geological Survey Memoir on the Postmasburg area by Dr. L.T. Nel.

Deposits associated with the Dolomite of the Transvaal System. The Dolomite of the Transvaal System contains small amounts of manganese. As a result of the chemical weathering of the rock this has at many places been concentrated at the surface in residual deposits of pyrolusite and psilomelane. Such deposits have been opened up at a number of localities in the Krugersdorp district of the Transvaal, the most important being on Warrenslaagte, a portion of the farm Weltevreden No. 40, Holfontein No. 35, Daniels Rust No. 19, Elandsvlei No. 23, and Brandvlei No. 21. Some of the deposits yield ore of great purity, but they are all of limited extent.

Deposits in Table Mountain Sandstone. Pyrolusite and psilomelane, accompanied in places by dufrenite, occur at many localities in the south-western districts of the Cape Province in veins and irregular replacements in Table Mountain Sandstone. The most extensive of these deposits is situated at Caledon. Its exploitation is unfortunately not feasible, as it happens to be the site of the Caledon Hot Springs and Sanatorium[2].

Mercury.

At Hectorspruit, situated south of Malelane Station on the Pretoria-Delagoa Bay Railway, cinnabar accompanied by metacinnabarite is disseminated through a belt of crushed quartzite from 4 to 5 feet (1.2 to 1.5 m) wide which can be traced at the surface for 400 yards (365 m). The quartzite belongs to the Moodies Series. The deposit was opened up some years ago and was

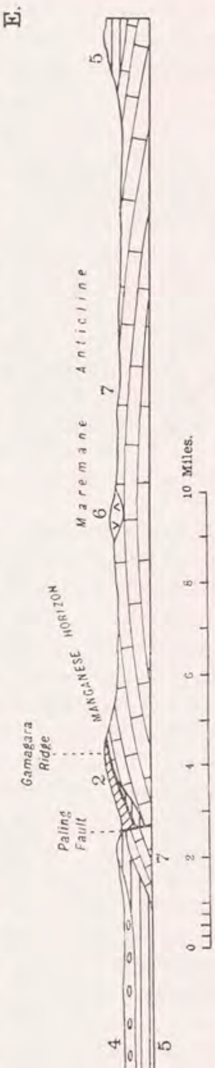

Fig. 51. Section showing the relation of the main Postmasburg Manganese Horizon to associated rocks, Postmasburg, north-west of Kimberley. 1 and 2. Lower Matsap Series. 3. Upper Griqua Town Series. 4. Ongeluk Volcanic Group. 5. Lower Griqua Town Series. 6. Blink Klip Breccia. 7. Dolomite.

[1] Hall, A. L. The Manganese Deposits near Postmasburg, West of Kimberley. Trans. Geol. Soc. S. Africa, 1926, pp. 17—46.

[2] Welsh, A. B. Report on Manganese in the South-West Districts of the Cape Province. Union of S. Africa, Dept. of Mines and Industries, 1917.

found in places to average between 2 and 3 per cent. of mercury. Adits driven into the hillside beneath the outcrop failed to locate the deposit. The mineralisation thus evidently does not persist to any depth.

Molybdenum.

Molybdenite occurs in association with cassiterite in a number of the tin deposits of the Bushveld Complex. The most important occurrence is on Groenvlei, No. 610, in the Waterberg tinfields. Here molybdenite is accompanied by notable amounts of bright yellow molybdenum ochre.

Molybdenite was also much in evidence in the "B. 6" pipe on Stavoren No. 1871, from which 3½ tons of 15 per cent. molybdenum ore were recovered in 1915.

In Impendhle County, Natal, molybdenite accompanied by molybdenum ochre and the rare mineral ilsemanite occurs disseminated through coarse sandstone belonging to the Molteno Division of the Stormberg Series, Karroo System[1]. The deposit has no economic significance.

Nickel.

The Union possesses large and varied resources of nickel ores. Hitherto there has been no output of the metal, but it promises to besome a valuable by-product of the Bushveld platinum industry.

Deposits of the Bushveld Igneous Complex. The biggest deposits unquestionably are those on the Merensky Platinum Horizon. Here, as previously pointed out, nickel occurs as pentlandite in association with chalcopyrite and pyrrhotite. The horizon has been traced for hundreds of miles, and the available reserve of low grade ore on it is practically unlimited. The average nickel content is only about 0.2 per cent. Tests have proved, however, that the bulk of the metal can be recovered by flotation, and as this class of platinum ore is to be worked on a huge scale, there can be no question that large amounts of nickel will be recovered.

Of a somewhat different nature are the nickel deposits occurring in the Norite Zone of the Bushveld Complex on the farm Vlakfontein, No. 902, situated west of the Pilandsberg in the Rustenburg District of the Transvaal. They take the form of isolated masses of irregular shape composed partly of disseminated, partly of poikilitic, and partly of solid sulphide ore, the country rock being bronzitite[2]. The principal ore minerals are pyrrhotite, pentlandite, and chalcopyrite. At and immediately below water-level the pyrrhotite has been largely replaced by marcasite, which forms perfect pseudomorphs after it. The ores contain notable amounts of goid and traces of platinum metals.

The Magmatic Nickel-Copper Deposits of Insizwa and Tabankulu, in Griqualand East. These deposits well known through the writings of du Toit[3] and Goodchild[4] occur near the lower contacts of great basin-shaped masses of gabbro-norite — a special phase of the well-known Karroo dolerite — which have been shown to be the remnants of a vast sill intrusive in the lower division of the Beaufort Series of the Karroo System. The individual gabbro masses which build prominent bush-clad ranges show pronounced density stratification. They range in composition from gabbro with interstitial micropegmatite at the top through olivine-gabbro and norite to picrite at the bottom. The lowest layer of all is gabbro, evidently a chilled contact phase of the parent magma.

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[1] du Toit, A. L. S. A. Jl. Sci. 1916, p. 153.
[2] Wagner, P. A. Memoir No. 21, Geol. Survey Union of S. Africa.
[3] Ann. Rept. Geol. Comm. Cape of Good Hope 1910—1911.
[4] Trans. Inst. Mining Metallurgy Bulletin 147, London 1916.

The nickel-copper minerals are associated with the picrite. In the Insizwa deposits both disseminated sulphide ore and massive sulphide ore are present. The former occurs as a big sheet-like body; the latter in veins, stringers and fairly extensive bodies of tabular shape. The disseminated sulphide ore is estimated by DU TOIT to contain from 2.5 to 3.5 per cent. of nickel plus copper, the two metals being present in approximately equal proportions. The ore minerals are pyrrhotite, chalmersite, pentlandite and chalcopyrite, with smaller amounts of bornite, niccolite, and zincblende. Subordinate amounts of the platinum metals — mainly palladium — are also present.

In the neighbouring gabbro-norite mass building the Tabankulu Range, smaller ore occurrences of the same type have been located.

Occurrence in the Barberton District, Transvaal. A very interesting nickel deposit was discovered in 1919 on the property of the Scotia Talc Company in the Barberton District, Transvaal. It takes the form of a tabular ore body 2 feet (0.61 m) thick in green talcose schist. This contains where sampled from 17.2 to 25.8 per cent. of nickel. The metal is present in the form of trevorite, a mineral new to science. It is a magnetic nickel-iron oxide belonging to the magnetite group, and having the composition $NiFe_2O_4$[1].

Occurrence on Blaauwbank No. 433, Waterberg District. On this farm, situated about 4 miles (6.4 km) west of the main workings of the Rooiberg Tin Mine, there outcrops a flat-dipping fissure vein ranging from 2 inches to 6 feet (0.05 to 1.8 m) in thickness, which carries notable amounts of nickel. Near the surface that metal is present in the form of solid masses of nickelbloom (annabergite) up to 2 feet (0,61 m), in thickness. At depth this gives place to patches of niccolite and gersdorffite embedded in a gangue of ankerite. The ore carries notable amounts of gold[2].

Radium and Uranium.

A series of pegmatite veins carrying uraninite in crystals and nodular masses up to several inches across are at present being opened up in the Gordonia district of the Cape Province in the valley of the Back River about 5 miles (8 km) from its confluence with the Orange.

Tin[3].

Tin ore ranks fifth in value among the mineral products of the Union. The principal deposits are situated in the Transvaal and occur in or in association with the Red Granite of the Bushveld Complex and in the felsites and sedimentary rocks of the Rooiberg Series forming the roof of the Complex.

[1] WALKER, T. L. "Trevorite, a Distinct Mineral Species". University of Toronto Studies, Geological Series, 1923, pp. 53—54.

[2] RECKNAGEL, R. Trans. Geol. Soc. S. Africa, 1908, pp. 105—106.

[3] KRIGE, A. V. "The Nature of the Tin Deposits near Kuils River." Trans. Geol. Soc. S. Africa, 1921, pp. 53—70.

KYNASTON, H. and MELLOR, E. T. "The Geology of the Waterberg Tin Fields." Memoir No. 4, Geol. Surv. Union of S. Africa, 1909.

McDONALD, D. P. "The Cassiterite Deposits of Leeuwpoort (No. 938). Trans. Geol. Soc. S. Africa, 1913, pp. 107—159.

NELLMAPIUS, E. H. "Notes on the Nature and Origin of the Vredehoek Tin Deposits." Trans. Geol. Soc. S. Africa, 1912, p. 1.

RECKNAGEL, R. "On some Mineral Deposits in the Rooiberg District." Trans. Geol. Soc. S. Africa, p. 83. 1909.

WAGNER, P. A. "Notes on the Tin Deposits in the Vicinity of Cape Town." Trans. Geol. Soc. S. Africa, 1909, p. 102.

WAGNER, P. A. "The Mutue-Fides Stavoren Tinfields." Memoir No. 16, Geol. Surv. Union of S. Africa, 1921.

WAGNER, P. A. "Gel Replacement of Cassiterite." Economic Geology, November, 1926.

The Deposits of the Bushveld Igneous Complex. The known occurrences are confined to the central part of the Complex, lying between Lat. S. 24° and Lat. S. 25° 30′ and Long. E. 27° 40′ and Long. E. 29° 20′. Within these limits the red granite and the granophyric rocks associated with it form a great composite sheet or lopolith. Wherever the upper portion of this sheet is exposed, or its original roof of felsite, felspathic quartzite or shale is preserved, cassiterite has been found; the richest deposits being apparently connected with anticlinal or domal structures in the original roof. In the eastern part of the Bushveld Complex, on the other hand, east and north-east of Middelburg, where identical geological conditions prevail, no cassiterite deposits have as yet been discovered.

The tin deposits of the Bushveld Complex are as varied as they are numerous. They bear, however, a common stamp which points to their having been formed during the same period of metallisation and under much the same conditions. Thus it can be shown of all the deposits that have been carefully studied that they have the same history and that their formation took place in a number of distinct stages; an early pegmatitic or magmatic stage having been succeeded by a pneumatolytic stage when cassiterite was deposited, and this in turn by one or more strictly hydrothermal stages.

The deposits are most conveniently classified as follows, according to the nature of the rock in which they occur:

1. Deposits in Red Granite;
2. Deposits in Granophyre;
3. Deposits in Felsite;
4. Deposits in the Sedimentary Rocks of the Rooiberg Series.

In certain areas, e. g. the Mutue Fides-Stavoren fields where there is exposed a continuous section from the granite to the Rooiberg Series, it is evident that the kind of country rock is correlated with the conditions of temperature and pressure under which the mineralization took place. Thus the deposits in granite, which are the lowest topographically and were evidently formed at the highest temperature and pressure, are essentially tin deposits. The deposits in the overlying granophyre, formed at a somewhat lower temperature and pressure, are cassiterite-scheelite-chalcopyrite deposits, and the deposits in the quartzites of the Rooiberg beds are cassiterite-chalcopyrite-wolframite deposits, which, moreover, contain considerable quantities of specularite. In other areas, however, there is no relation between the nature of the mineralisation and that of the country rock. Thus the lode deposits of the Rooiberg and Leeuwpoort fields, though they are in the Rooiberg beds, are essentially tin deposits, tungsten and copper minerals being quite subordinate to cassiterite.

1. Deposits in Granite.

The most important deposits in granite are those of the Potgietersrust fields, situated 15 miles (24 km) north-west of Potgietersrust. They embrace a narrow strip of rugged country some 14 miles (22.5 km) in length paralleling the Potgietersrust Platinum Belt, previously referred to, which is situated some 10 miles to the east.

The tin deposits occur in a great composite sheet of red granite, dipping at an angle of about 15° to the west, which was apparently slightly later than a thick overlying sheet of granophyric rocks which in turn was intruded in a succession of felsites and shales that here formed the roof of the Bushveld Complex. The upper limit of the tin-bearing granite is defined by a persistent pegmatite zone containing a number of distinct sheets of coarse pegmatite which clearly crystallised in place from above downward; the big parallel quartz crystals of which the pegmatite is largely composed all pointing in that direction.

The main granite sheet is, as already indicated, composite in character. It consists in its basal portion of porphyritic granite. This is succeeded by alternations of coarse grained pink and red granite and aplitic granite. Above this there follows a thick zone of miarolitic granite which in turn merges into fine-grained aplitic granite showing pronounced pseudostratification. The aplitic granite is limited above by the pegmatite zone already referred to, and if our interpretation be correct, probably represents a chilled marginal phase of the coarse red granite.

The most important deposits occur immediately or at a short distance below the pegmatite zone on the farms Groenfontein No. 871, Roodepoort No. 813 and Zaaiplaats No. 236. They occur in the coarse miarolitic granite, in the fine-grained granite overlying it, and there are also important deposits following the lower contact of the pegmatite and in the pegmatite itself.

The deposits are of four main types, namely:

a) Pipes;
b) Irregular impregnations in miarolitic granite;
c) Replacements along fissures in the fine-grained aplitic granite, or along the pseudo-bedding planes of that rock;
d) Tabular replacements following the lower contact of the pegmatite or in the pegmatite.

a) Of these the pipes are by far the most interesting and important. They are of the nature of irregular tubular bodies of mineralized altered granite of circular or oval cross section. They range in greatest diameter from a foot to 40 feet (12 m) and descend at varying angles into the granite in a general west-north-west—east-south-east direction. The pipes occur in groups, and it has been the general experience that those outcropping in close proximity to one another unite in depth, forming complex branching ore bodies.

On Zaaiplaats, for example, what were originally taken to be about 25 separate pipes have resolved themselves into two main pipe systems, known respectively as the "No. V—VI" and the "No. XIII" pipes (see Fig. 52). Of these the former have been followed for a distance of over 2000 feet (610 m) measured along the incline, and the "No. XIII" pipe for over 2500 feet (762 m), equivalent to a vertical depth of 688 feet (210 m).

The pipe matter is of two main types. Commonly it consists of a soft yellowish-grey brown-spotted aggregate composed of crystals of cassiterite averaging about 1.5 mm across, scattered through a matrix made up mainly of small flakes of sericite (gilbertite), in which the outlines of much altered grains of felspar can usually be made out. A good deal of calcite is generally present, and isolated relics of the original quartz of the granite are sometimes to be seen. In addition chlorite and fluorspar and one or more of the ore minerals, to be subsequently enumerated, may be present.

The other type of ore is essentially felspar-cassiterite rock, being composed largely of red or pink microperthite indistinguishable from that of the surrounding granite except in that it often exhibits idiomorphic outlines. Subordinate amounts of gilbertite, chlorite and purple fluorspar are generally present, and the cassiterite may be accompanied by arsenopyrite, pyrite and chalcopyrite. This type of ore has clearly developed as a result of the replacement by cassiterite of the quartz of the normal granite, while the felspar remained unattacked.

In the type first dealt with the replacement of quartz by cassiterite was succeeded by the replacement of felspar by sericite, calcite and other minerals. In some pipes this soft sericitic ore has suffered secondary impregnation by quartz. In others the pipe matter has been largely replaced by grey or brown chalcedonic silica evidently deposited as silica gel.

The ore is sometimes zonally banded parallel to the outer periphery of the pipes.

In the upper parts of the "No. V and VI" pipes on Zaaiplaats there were found big elongated vughs lined with crystals of fluorspar, quartz, calcite, chalcopyrite,

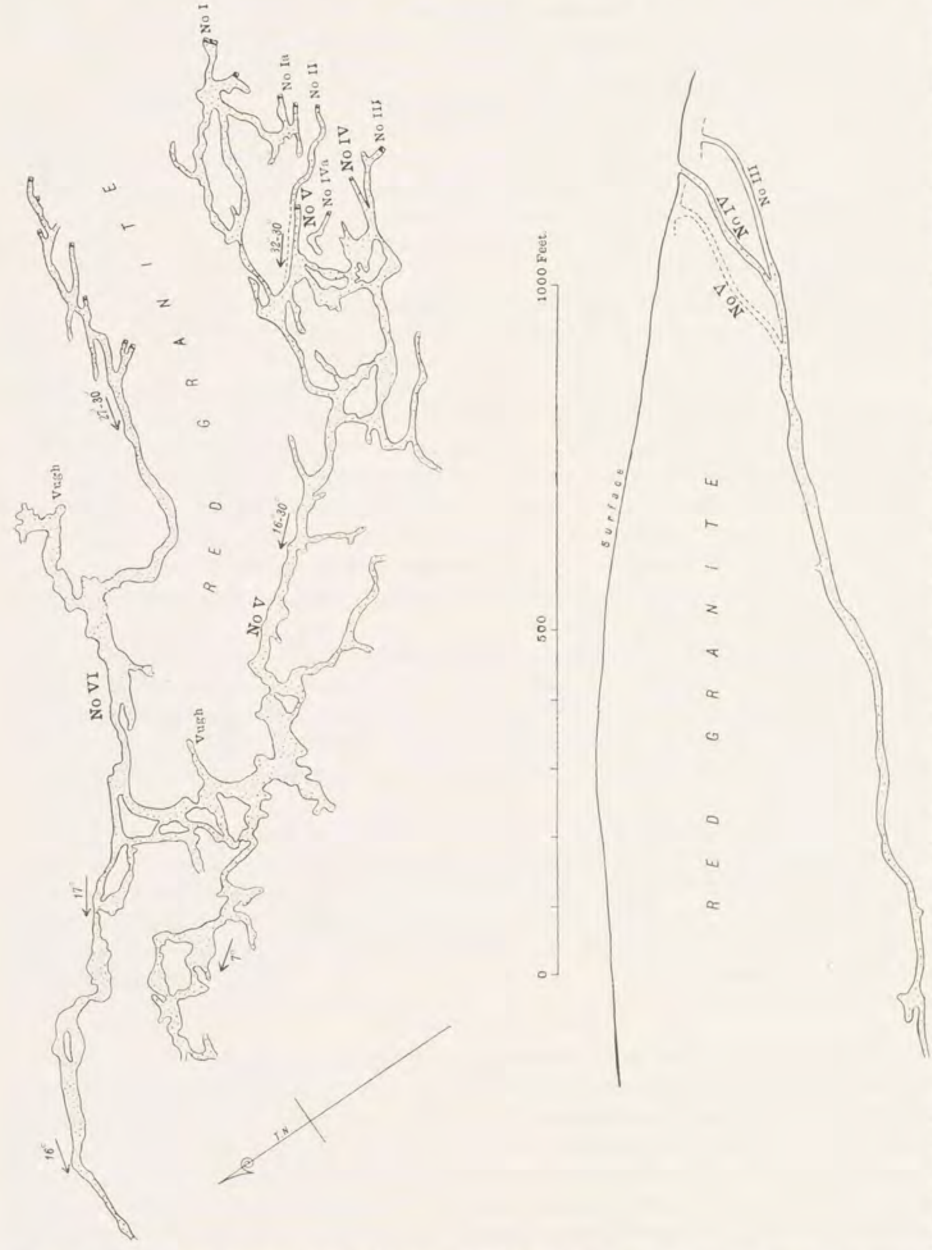

Fig. 52. a) Plan of Nos. IV, V and VI Tin-bearing Pipes on Zaaiplaats No. 1328, Potgietersrust District, Transvaal Province.
b) Longitudinal Section through No. IV and No. V Pipes, Zaaiplaats.

galena, and zincblende; the three last-named minerals sometimes forming concentric crusts.

Sometimes there is a direct transition from ore through sericitised granite to unaltered granite. Frequently, however, the pipe-matter proper is encased in remarkable "tourmaline-rings", from ½ inch to 4 feet (0.0127 at 1.22 m) in thickness, composed of radial and fan-shaped aggregates of black tourmaline needles in a matrix of white quartz. These rings are, as a rule, in turn surrounded by a narrow zone of white quartz and this by a zone of fresh-looking granite which under the microscope is found, however, to owe its fresh appearance to secondary impregnation by quartz, generally accompanied by calcite. Outside this follows a zone of granite in which the biotite of that rock, and sometimes the felspar, are replaced by sericite, and then the normal granite.

Some of the pipes have proved remarkably rich, but in all of them rich sectors have alternated with poor and barren sectors occupied by more or less altered granite free from cassiterite. The latter generally coincide with the sectors of the pipes showing flat dips.

As to the origin of these remarkable pipes, it is quite certain that they are independent of fissures in the granite. They evidently date from a period when the state of consolidation of that rock did not permit the formation of fissures. These, however, may have been represented by potential planes of weakness.

Evidence collected by the writer of recent years renders it highly probable that the pipes have developed from trains of miarolitic zones in the granite comparable with the trains of bubbles found in glass melts. The great bubble trains have apparently been localised by an anticlinal structure in the rocks originally overlying the granite. He hopes to develop this theory in a special memoir on the deposits.

c) Of the other occurrences the most interesting are the replacements below the pegmatite. These as a rule follow well defined lines of fissure in that rock and in the fine-grained aplitic granite below it. Here also cassiterite has replaced quartz in preference to felspar, and one finds perfect pseudomorphs of cassiterite after crystals of quartz. The felspar is usually sericitised and the granite surrounding these deposits has been converted into a typical greisen. On Groenfontein No. 871, where these deposits attain their greatest importance, the strike of the productive fissures ranges from E. and W. to W. by N.

Considerable amounts of cassiterite have been obtained from the same type of replacement deposits in coarse red granite, also in some instances below big bodies of pegmatite on the Mutue Fides Tinfields situated some 70 miles (113 km) to the south-south-east. Widespread greisenization of the surrounding granite is a feature of the deposits.

On the farm Vlaklaagte, No. 39, situated 54 miles N. E. of Pretoria, there were discovered in 1905 small bodies of stanniferous greisen in coarse red granite. Some of this greisen was very rich, carrying up to 40 per cent. of tin. The ore bodies, on being opened up, proved to be of such limited extent as to have no economic significance. The greisen consists of crystals of cassiterite imbedded in a greyish groundmass of quartz, sericite and topaz; this being the only authenticated[1] occurrence of topaz in the Bushveld Tin Deposits.

2. Deposits in Granophyre.

In these deposits typically developed on the farm Stavoren, No. 1872, in the south-eastern part of the Waterberg district, the ore minerals occur as replacements and vugh fillings in pipes, veins and sheet-like bodies of felspar-rich pegmatite, the pipe-form predominating. The deposits are remarkable for the rich and varied assortment of minerals which they contain and for the strikingly handsome appearance of much of the ore. The chief ore minerals are cassiterite, scheelite, chalcopyrite, arsenopyrite, molybdenite, bismuthinite, galenobismutite, galena and zincblende. The gangue minerals include felspar, quartz (in four generations), calcite,

[1] cf. BECK, R. Zeitschr. für Prakt. Geol. 1906, pp. 205—209.

fluorspar, raven-mica, specularite, sericite and chlorite. The deposits are extremely erratic as to ore content.

It has been suggested that the pegmatite pipes were themselves formed by the replacement of the granophyre and this is not improbable.

3. Deposits in Felsite.

These have so far proved very disappointing. They are, as a rule, rather ill defined and patchy, consisting of small irregular veins and pockets carrying fairly coarse cassiterite sometimes distributed over a fairly considerable width of country rock. On the farms Rhenosterhoek Spruit No. 1608 and Uitkyk No. 2241, situated 30 miles (48 km) west of Nylstroom, there are being opened up a series of parallel vertical tin-bearing crush zones in felsite.

4. Deposits in the Sedimentary Rocks of the Rooiberg Series.

These include the interesting lode deposits of the Rooiberg and Leeuwpoort Tin Fields, and a lode on Doornhoek No. 896 in the Waterberg District.

The Rooiberg Tin Fields. These lie some 40 miles (64 km) west of Warmbaths, the most important deposits being situated on the farms Olivienbosch No. 939, Weynek No. 763, Blaauwbank No. 433 and Nieuwpoort No. 11, where there are extensive ancient native mine workings. The deposits take the form of well-defined lodes with which are connected large irregular replacements generally following the bedding planes of the enclosing, flat-dipping, felspathic quartzites. The lodes appear at first sight to form a very complicated network and the whole field has been aptly likened to a gigantic "stockwerk". On closer investigation, however, the lodes in the Rooiberg area at any rate are found to belong to three main systems, namely,

a) those striking approximately north and south and dipping at 60° to the east;
b) those striking approximately north-west and south-east, and dipping either vertically or very steeply to the south-west;
c) those striking north-east — south-west and dipping either to the south-east or to the north-west.

The lodes are of the nature of replacements along narrow fissures up which the mineralising vapours and solutions ascended; most of the fissures themselves being of the nature of master joints. Actual fissure filling has played a quite unimportant role. The majority of the veins are narrow, averaging between 2 and 3 feet (0.61 and 0.91 m) in thickness, and most of the ore has been obtained from the big replacement deposits, connected with the lodes, to which reference has already been made. These are of quite irregular shape, and are known locally as „supplementary fillings".

The ore varies greatly in appearance. In places (Progress Lode) it consists of a felted aggregate of cassiterite, fine-gained black tourmaline, sericite and quartz, which may or may not be accompanied by other ore and gangue minerals. In other places it is conspicuously brecciated (Union and Pyritic lodes), fragments of the earlier-formed lode-matter being imbedded in a matrix of later iron-lime-carbonates. The principal ore minerals are cassiterite, pyrite, and chalcopyrite. Galena, zincblende and gold occur as accessory minerals. The gangue minerals, arranged more or less in the order of their arrival, are red orthoclase, quartz, tourmaline, specularite, sericite, fluorspar, chlorite, sideroplesite, ankerite and allied carbonates.

These deposits have produced considerable amounts of cassiterite, and new discoveries are continually being made. The cassiterite, unfortunately, does not persist to any depth, generally giving out rather abruptly at about 100 feet (30.5 m) below the present surface, which suggests that the vertical range of ore deposition was here very small.

The Leeuwpoort Tin Field. The Leeuwpoort tinfield, which of recent years has been the most productive in the Transvaal, is situated on the farm Leeuwpoort No. 1336 about 10 miles (16 km) south of the main Rooiberg workings. The tin deposits again take the form of replacement veins following narrow fissures, and of irregular replacements along interlacing cracks and fractures. These latter type of deposit, however, here play a less important role than at Rooiberg. The lodes fall into three main systems, namely:

1. those trending roughly north and south; examples the "Adit", "H. G." and "West End";
2. those trending roughly north-north-east—south-south-west; examples the "Spruit", "Gap" and "Cemetry";
3. those trending roughly west-north-west—east-south-east; examples the "New Strike", "South" and "Nek".

The lodes are less steeply inclined than the Rooiberg lodes, the dip rarely exceeding 40° and being generally below this. They range in thickness from 1 foot to 4 feet (0.30 to 1.22 m), the average being about 18 inches (0.46 m). The lode matter in the more normal lodes consists of cassiterite accompanied by various combinations of the following minerals: red orthoclase, quartz in several generations, tourmaline, magnetite represented by martite, specularite, pyrite, chalcopyrite, apatite, fluorspar, sericite, chlorite and ankerite.

The ore is, as a rule, devoid of any definite structure, but sometimes it is banded parallel to the lode walls. In the "H. G." lode and the big irregular replacement deposit to the north-east of it the ore is a soft white pulverulent mass composed of sericite, kaolin and quartz, sometimes accompanied by iron oxides, through which are scattered crystals of cassiterite and patches of black tourmaline.

The Leeuwpoort occurrences differ from those of the Rooiberg fields mainly in that tourmaline is here subordinate. The range of ore deposition was evidently much greater than at Rooiberg, boreholes recently put down having struck rich ore at a depth of 400 feet (122 m) below the surface.

Doornhoek No. 896. On this farm a good deal of tin was obtained between 1906 and 1909 from a well defined lode cutting obliquely across the Sterk River Shales of the Rooiberg Series. The lode strikes east and west and dips to the north at 60°. It averages 18 inches (0.46 m) in thickness and consists of brecciated and highly altered fragments of the country rock cemented by quartz, with which in places cassiterite, sericite, fluorspar, tourmaline, specularite, magnetite, and hematite are associated. The cassiterite is exceedingly fine-grained and cannot as a rule be identified with the unaided eye. The shales on either side of the lode have suffered tourmalinisation.

Tin Occurrence of the Cape Province. The only tin occurrences so far discovered in the Cape Province are situated near Cape Town on the slopes of Table Mountain, and in the granite of the Bottelary-Stellenbosch Mass, and the rocks of the Malmesbury Series near the intrusive contact of this granite.

Four main types of deposit may be distinguished:

1. Veins and associated impregnations in granite;
2. Stringer lodes in the rocks of the Malmesbury Series;
3. Saddle veins in the rocks of the Malmesbury Series;
4. Alluvial deposits derived from the disintegration of the primary occurrences.

Of the primary occurrences only those belonging to types 1. and 2. have so far been found worth working, and operations were in each case soon suspended. The most important deposits are on the farms Langverwacht and Hazendal, situated 18 miles (29 km) east of Cape Town. They take the form of quartz veins in fine-grained aplitic granite traversing coarse porphyritic granite. These veins carry coarse cassiterite in association with wolframite, molybdenite, arsenopyrite, chalcopyrite, muscovite and tourmaline. Wolframite disappears below a depth of 150 feet (46 m).

The disintegration of these deposits has given rise to the formation, in a broad valley and some of the creeks traversing the farm Langverwacht, of fairly considerable alluvial cassiterite deposits which were at one time worked on a big scale. It is from these deposits that the greater part of the output of tin ore of the Cape Province, amounting to date to 566 tons valued at £ 60000, has been derived.

Tungsten.

Scheelite occurs in considerable quantities in some of the tin deposits on the farm Stavoren No. 1871 in the Waterberg District, Transvaal[1]. During the Great War some 30 tons of the mineral were recovered, but owing to the big drop in the price of tungsten immediately after the cessation of hostilities, its recovery was abandoned.

Wolframite occurs in association with cassiterite in the deposits on Mutue Fides No. 1844, Groenvlei No. 610, and Appingadam No. 1870 in the Waterberg District; also in the quartz lodes on the farmes Langverwacht and Hazendal situated 18 miles (29 km) west of Cape Town.

Vanadium.

Vanadinite, the chloro-phosphate of vanadium, occurs in association with lead ores at various localities in the Transvaal. The most extensive deposits so far opened up are situated on the farm Kafferskraal No. 214, 15 miles south-south-east of Zeerust in the Marico District, Transvaal[2]. Here vanadinite in well formed hexagonal crystals occurs in the uppermost portion of the Dolomite Series in irregular lyers following the bedding of soft manganese earth that has here replaced the dolomite. The mineral also occurs in steeply dipping stringers cutting across the bedding of the manganese earth, and in irregular pockets and as an incrustation on joint planes. It is clearly of supergene origin, its lead content having been derived from galena. In places are found irregular nodules showing a kernel of galena surrounded by concentric layers of pyromorphite and vanadinite, the vanadinite encrusting the pyromorphite.

Attempts at concentrating the vanadinite on a large scale have so far failed.

C. Non-Metallic Minerals.

Asbestos[3].

South Africa has vast resources of asbestos and produces a greater range of fibre than any other country. The principal varieties are:

1. Chrysotile or White asbestos, which occurs in the Transvaal and Natal. The most important deposits are situated near Kaapsche Hoop in the Barberton District, Transvaal, where chrysotile asbestos of excellent quality forms numerous veins of the cross-fibre variety in an extensive belt of serpentine belonging to the Jamestown Series of the Swaziland System. The most important producer is the New Amianthus Mine.

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[1] cf. Wagner, P. A. Memoir No. 16, Geol. Surv. Union of South Africa, 1921.

[2] cf. Fergusson, M. and Wagner, P. A. Vanadinite in the Marico District. S. Afr. Journal of Industries, 1921, pp. 911—913.

[3] The asbestos occurrences of the Union are fully dealt with by A. L. Hall in the following publications: "Asbestos in the Union of South Africa", Memoir No. 12, Geol. Surv. Union of S. Africa, Pretoria, 1918; "The Asbestos Resources of the Union of South Africa." S. A. Jl. Industries, Nov. 1924; "On the Asbestos Occurrences near Kaapsche Hoop in the Barberton District." Trans. Geol. Soc. S. Africa, 1921, pp. 168—181; "Further Notes on the Asbestos Occurrences near Kaapsche Hoop". Trans. Geol. Soc. S. Africa, 1923, pp. 31—49.

A detailed description of the Amianthus Mine is contained in an unpublished report by H. Merensky.

Less important deposits of chrysotile asbestos occur in the Carolina District of the Transvaal in serpentinised dolomite belonging to the Transvaal System; and in serpentine at Isitilo in the Tugela Valley, Natal.

2. Crocidolite or Blue asbestos of which there are vast deposits in the banded ironstone of the Lower Griquatown Series in Griqualand West, and lesser deposits in the basal portion of the Pretoria Series in the Lydenburg and Pietersburg Districts of the Transvaal.
3. Amosite or Iron-amphibole asbestos of which there are very large deposits in the Pretoria Series in the Lydenburg District of the Transvaal.
4. Tremolite asbestos of the slip-fibre variety which occurs near Pomeroy in Zululand.
5. Asbestic, consisting of a matted aggregate of fibres of antophyllite, of which there is a big deposit on the farm Korea, situated 50 miles west of Waterpoort Siding in the Zoutpansberg District, Transvaal.

The table of outputs given below shows that the industry is rapidly expanding, and, with the ever increasing demand for asbestos and asbestos products, there is no knowing to what dimensions it may ultimately attain.

Most of the asbestos produced in South Africa is exported to Europe and America, but a certain amount is used in the country for the manufacture of asbestos cement tiles and other products.

There has been a great deal of controversy as to the relative merits of the two chief types of asbestos, namely, white and blue. It is becoming increasingly apparent that each has its own sphere of utility. It is of interest, however, to record that tests made at the National Physical Laboratory have shown that blue asbestos is one of the best practical non-conductors of heat, being about 20 per cent. better than white.

Asbestos Output of the Union of South Africa.
(Short Tons)

Year	Cape Tons	Transvaal Tons	Natal Tons	Total Union Tons	Total Union Value Sterling
1910[1]	680.25	10.5	2.5	693.25	10801
1915	2082.9	55.5	—	2138.4	35899
1920	3525	3541.5	45	7112.3	114195
1925	25.40	7627	—	10168	152115

Barytes.

There are important deposits of this mineral near Riversdale in the Cape Province, and it occurs in veins on the farm Vergelegen, No. 1695 on the Magalakwin River, 80 miles (129 km) north-west of Pietersburg in the Transvaal.

Building and Ornamental Stones.

South Africa has very large resources of stones suitable for building and ornamental purposes. Up to the present, however, they have only been exploited to a small extent. Of the stones that have been and are being used mention may be made of the following:

Granite. Several varieties of the Old Grey Granite are quarried between Johannesburg and Pretoria, the best known is that obtained at Witkoppen, 14 miles (22.5 km) north of Johannesburg. This is a medium-grained biotite granite with barely perceptible foliation. It has a very high crushing strength, and is on this account largely used for the foundations of public buildings, bridges and the like.

[1] For the last seven months of the year.

A very handsome pale yellowish-grey variety of the Old Granite is quarried at Pietersburg.

The Paarl Granite, so much in evidence near the town of that name, is extensively used in the Cape Province also to some extent in the Transvaal.

Syenite[1]. The Southern Transvaal probably stands unrivalled in the variety of beautiful syenites which it contains. A start has been made to use them for ornamental purposes, and as they become better known, they will doubtless be in great demand.

Norite. A rather dark-coloured variety of the norite of the Bushveld Complex is quarried on a considerable scale at Bon Accord north of Pretoria; it is very largely used for shop fronts, tombstones, curbing, and also to some extent for building purposes.

Dolerite and Diabase. These rocks which are very widely distributed have been utilised to some extent for building purposes, but their sombre appearance militates against their more general use.

Sandstone. The Ecca and Stormberg Series of the Karroo System yield many varieties of sandstone. The best and most reliable of these is that quarried at Flatpan, situated near Coalbrook in the northern Orange Free State. It is a freestone of dull grey or bluish-grey colour and of pleasing appearance. It is seen to great advantage in the upper storeys of the Union Buildings, Pretoria. Rather less satisfactory sandstone is quarried at Steenpan which adjoins Flatpan, and at Klippan in the same neighbourhood.

Sandstone is also quarried at many other localities in the Transvaal and Orange Free State. One of the most handsome varieties is that outcropping on the sides of Buiskop near Warmbaths.

Marble. There are very important deposits of white and coloured marble on the farms Marble Hall, No. 248 and Scherp Arabie No. 367 situated in the Bushveld about 100 miles (160 km) north-east of Pretoria[2]. Recently deposits of fancy marble of various colours and patterns have been discovered on the farm Buffelspoort, No. 370, situated 30 miles (48 km) north of Brits in the Transvaal.

There are also deposits of bluish-grey, grey and yellowish marble in the Malmesbury beds in the Van Rhyns Dorp district north of Cape Town. One of them on the farm Klipdrift, situated on the Holle River, a tributary of the Olifants, is being worked.

Slate. Slate suitable for roofing is quarried near Zwartruggens in the Western Transvaal. It is not a true slate, but none the less cleaves very readily along its bedding planes, which are generally covered with minute glistening flakes of white mica.

A more thickly bedded flagstone is quarried at Pretoria and is extensively used for curbing and paving.

Clays.

Ordinary clays suitable for brick and tile making have a wide distribution in the Union, and are utilised at many localities in the Transvaal, Natal and the Cape Province. Some of the best bricks produced in the country are, however, made from a mixture of crushed shale and clay, or from crushed shale alone. Shale belonging to the Upper Dwyka and Pretoria Series is used for this purpose.

Fire-Clay. Fire-clay occurs at a number of localities in the coal measure series of the Karroo System sometimes immediately beneath seams of coal. The best-

[1] WAGNER, P. A. "On Building and Ornamental Stones in the Transvaal. S. A. Jl. Ing., Aug. 1924.

[2] TREVOR, T. G., WAGNER, P. A. S. Afric. Jl. Ind., Vol. II, pp. 634-650.

known deposits are at Boksburg, Olifantsfontein and Vereeniging in the Transvaal, where there are important establishments for the manufacture of refractory wares.

Kaolin. There are important deposits of kaolin on the farm Kranzfontein south of Boons Siding on the Krugersdorp-Zeerust Railway; near the White River Settlement in the Barberton District; at Grahamstown; close to Padleys Station on the Durban-Maritzburg railway; on the Cape Flats and in Namaqualand. The Kranzfontein and Grahamstown kaolins are being successfully employed for making pottery.

Coal[1].

The Union of South Africa has, in proportion to its requirements actual and prospective, very large reserves of workable coal. These have already proved of the utmost value to the industries of the country, and will doubtless become increasingly valuable as these develop.

The chief deposits are in the Coal Measures Series (Middle Ecca) of the Karroo System. There are less important seams in the Beaufort and Stormberg Beds, and thin layers of impure coal also occur in the White Band horizon of the Dwyka Series.

The Coal Measure Series of the Karroo System, with which we are more particularly concerned, is developed in the Transvaal, Orange Free State, Natal and Zululand, but is absent in the Cape Province where the Ecca Series attains its greatest thickness (see Fig. 53).

The Coal Measures are made up of sediments of every degree of coarseness from conglomerates to shales, intermediate types like grits and sandstones predominating. Thin beds of iron ore, to which reference has already been made, are in places intercalated with these rocks. The measures are, for the most part, disposed horizontally or nearly so. The coal has a characteristically banded appearance, being made up of alternations of thin layers of bright coal (clarain and vitrain) and dull coal (durain) or shaly matter. Much the greater part of it may be classed as bituminous[2] coal rather high in ash. The Natal coals contain the least ash. The coal, speaking generally, is rich in sulphur. This is present mainly as pyrite or marcasite irregularly distributed through the coal in crystals, crystal aggregates, or in veins and seams. The bulk of the sulphur can in consequence be removed by washing.

The physical conditions under which the coal was deposited appear to have differed somewhat from those under which many of the better known coal seams in other parts of the world were laid down. This applies particularly to the Transvaal area where the coal was deposited not in vast swamps or marshes, but in more or less isolated basins, with uneven floors, on the margins of which ridges of older rocks rose abruptly in some instances to a height of 200 feet above the general level. The common absence of "under-clays" below the seams and the frequent presence of shaly or even of sandy bands in the coal seams led at one time to the belief that all South African coals were of drift origin. This view, however, is negatived by the occasional occurrence in connection with some of the seams of fossil stumps and

[1] KOTZE, R. N., KYNASTON, H., and ROGERS, A. W. "The Coal Resources of South Africa" Rep. Geol. Surv. Union of South Africa, 1911, pp. 97—100.

TREVOR, T. G. and VAUGHAN, J. E. "Coal", Official Handbook of the Union of South Africa, and "Industrial Development in South Africa", Pretoria, 1924, pp. 165-171.

WYBERGH, W. J. "The Coal Resources of the Union of South Africa"; Vol. I. The Coalfields of Witbank, Springs and Heidelberg, and of the Orange Free State; Vol. II. The Inland Coalfields of Natal, Memoir No. 19, Geological Survey, Union of South Africa. Vol. III. The Coalfields of the Eastern and South-Eastern Transvaal, Springbok Flats, Zoutpansberg, and of the Cape Province. Memoir No. 19, Geological Survey, Union of South Africa, 1928.

[2] According to the classification used by the United States Geological Survey (Professional Paper 100-A, 1917, 3), most of the coal would be described as high-rank bituminous or as intermediate between that class and low-rank semi-bituminous.

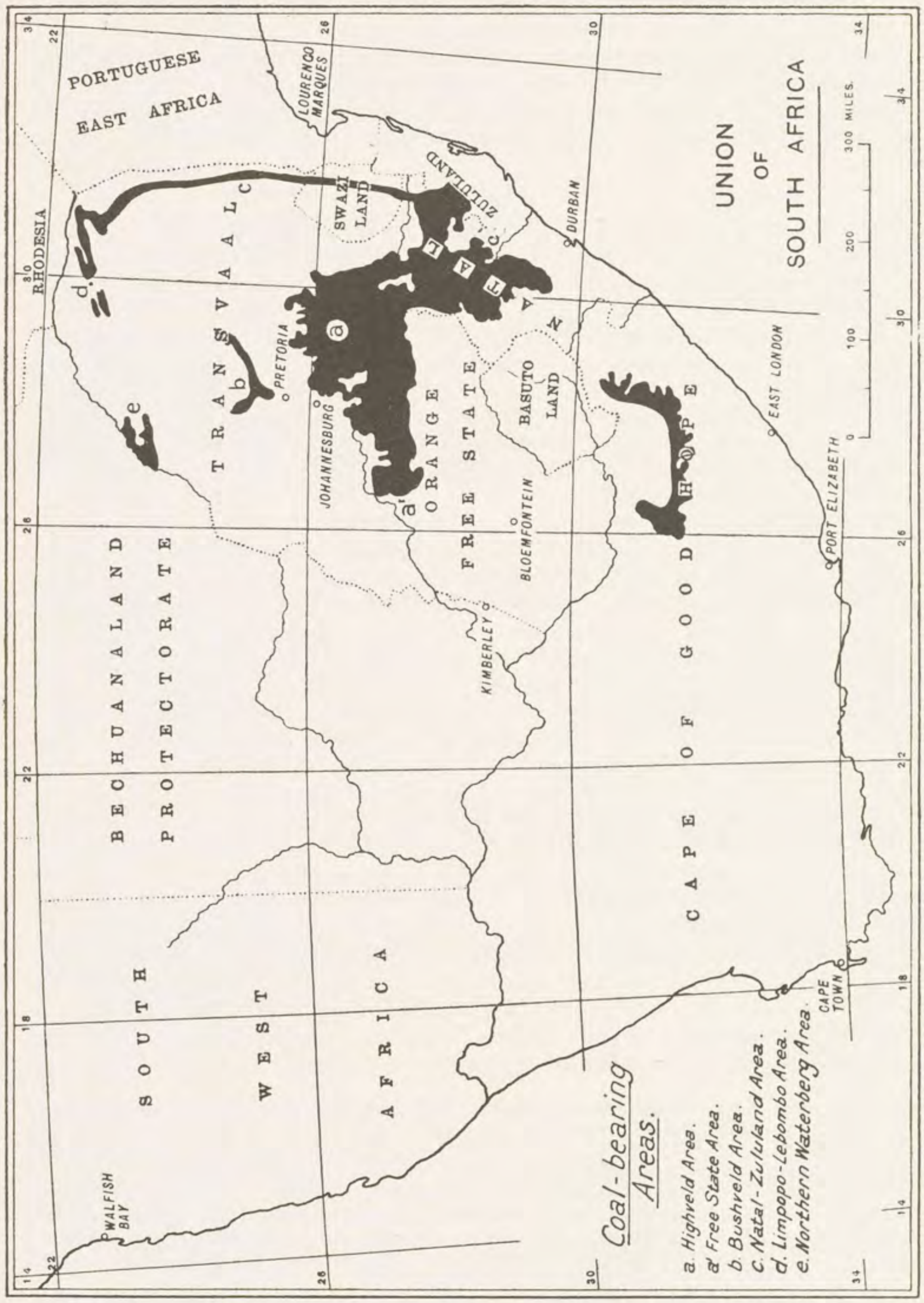

Fig. 53. Outline Map showing the Coal-bearing Areas of the Union.

roots of large Coal Measure plants in the positions in which they grew; also by the persistent character of some of the seams with a comparatively low percentage of foreign matter.

The chief coalfields of the Union may be classified on a geographical basis as follows:

I. The Coalfields of the Transvaal.
II. The Coalfields of the Orange Free State.
III. The Coalfields of Natal and Zululand.
IV. The Coalfields of the Cape Province.

They will be dealt with in the order given.

A. The Coalfields of the Transvaal.

These are the most extensive and embrace five separate areas, namely,

a) The Highveld or Southern Transvaal area;
b) The Bushveld area;
c) The Lebombo area;
d) The Limpopo area;
e) The Northern Waterberg area.

a) Of the foregoing only the **Highveld or Southern Transvaal** area is at present being exploited. It includes a number of separate coalfields, namely:

1. The Witbank Field. This is the most important in the Union and is responsible at the present time for forty percent of the total output. It occupies a considerable area in the southern part of the Witbank district, over which the Coal Measures extend as a horizontal sheet with an average thickness of about 200 feet (60 m). There are five and in places six distinct seams lying horizontally above one another. The principal seams in ascending order are known as the "Numbers 1, 2, 3, 4 and 5". They have an aggregate thickness of 57 feet (17 m). Of this total the average thickness worked is 10 feet (3 m), ranging from 6 to 15 feet (1,8 to 4,6 m) in different mines (see Fig. 54).

The "No. 2" is the main seam and furnishes most of the coal produced on the field. It is up to 23 feet (7 m), in thickness, but only in the lower part is the coal of good enough quality to be worth working. The portion mined ranges from 4 to 15 feet (1,2 to 4,6 m). The coal produced contains from 12 to 16 per cent. of ash. It is a rather dull, hard, steam coal, which stands handling and transportation extremely well.

All the other seams with the exception of the "No. 4" are, or have been worked at one place or another.

The total available reserves of coal in the Witbank area were estimated in 1922 by Wybergh at 7956000000 short tons having an average evaporative power of11.19. Of this total it was estimated that there are 1348799000 tons with evaporative power ranging from 12.0 to 13.5.

2. The Ermelo-Carolina fields. These are situated in the Ermelo district and in the adjacent portion of the Carolina district. There are two seams, of which the lower contains coal of good quality. It averages slightly under 6 feet (1,8 m) in thickness. No attempt has been made so far to estimate the available reserves in this area.

3. The Springs Field. This is situated west of Johannesburg and, though small and containing coal of relatively poor quality, is of great industrial importance owing to its proximity to the Witwatersrand goldfields. Several seams have been mined. The available reserves are given by Wybergh at 485000000 short tons with an evaporative power of 9.08.

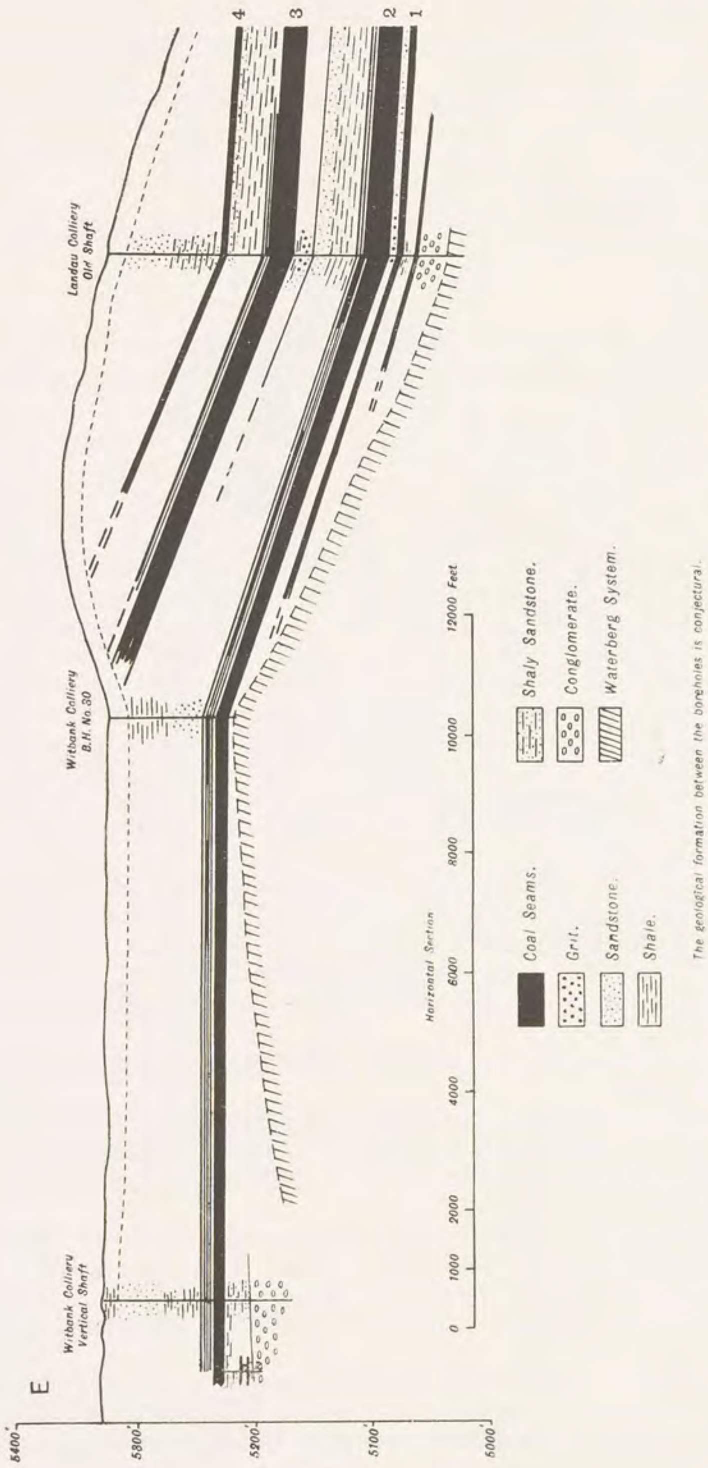

Fig. 54. Section across the Witbank Coalfield, eastern Transvaal.

4. The Heidelberg Field. This includes the important South Rand Coalfield estimated to contain 8064000000 tons with an evaporative power of about 10.

5. The Nigel Field. This contains three small areas of coal of inferior quality. One of them was worked for a short time at one locality.

6. The Vischkuil-Delmas Field. This contains three seams, but only the lower part of one of them is being worked. The reserves are estimated at 1629000000 tons with an evaporative power of 10.

7. The Belfast Coalfields. These include two small outliers of Coal Measures in the neighbourhood of Belfast. A thick seam of rather poor coal is being worked at two localities.

8. The Vereeniging Field. This is a direct continuation northward across the Vaal River of the Orange Free State Field.

9. Undeveloped Coalfields. There are also undeveloped coal-bearing areas in the Bethal, Standerton, and Wakkerstroom districts of the Transvaal, about which very little is at present known.

b) The Bushveld Area.

This is an area beginning about 30 miles (48 km) north of Pretoria and occupying an oval-shaped tract measuring roughly 70 (113 km) by 30 miles (48 km), the longer axis of the area being directed northeastward. Coal seams of considerable thickness have been struck in boreholes and in one shaft. The coal appears throughout to be of inferior quality, and, as it is less favourably situated with regard to the principal centres of consumption than the fields already dealt with, which also yield much better coal, there is no prospect of its being worked in the near future.

Between the main Bushveld area and Pretoria is a small outlier of coal measures, which was at one time worked at the Rogerston Colliery.

c) The Lebombo Area.

This contains a strip of coal measures some 6 miles (9.6 km) wide which extends along the eastern boundary of the Transvaal and Swaziland for a distance of several hundred miles and then swings round to the west into the northern part of the Zoutpansberg District. The coal appears to be of good average South African quality, but is anthracitic in character, its alteration being doubtless due to heat from the great overlying mass of the Lebombo lavas.

d) The Limpopo Area.

This includes a number of detached areas south and south-east of Messina in the Zoutpansberg. The coal has so far only been opened up at one locality, namely, Lilliput. The seam here exposed is 3 feet (0.91 m) in thickness and the coal of rather inferior quality.

e) The Nothern Waterberg Area[1].

This is bounded on the north and west by the Limpopo River, on the east by the Pongola River, and on the south by an unconformity or fault with an east and west trend passing a little to the north of the Rooibok Hills. There are two seams. The lower yields coal of much the same quality as that worked in the Southern Transvaal, while the coal of the upper seam is of a more bituminous character than that so far opened up anywhere else in South Africa. It will probably be long before these inaccessible fields are worked.

[1] Trevor, T. G. and du Toit, A. L. South African Journal of Industries, 1922, p. 164.

B. The Coalfields of the Orange Free State.

These fields, situated in the nothern part of the Orange Free State, are of great extent, having an area of probably 10000 square miles (26000 qkm). The coal seams vary in number from one to four, and their aggregate thickness from 6 to 53 feet (1.8 to 16 m). The seams are persistent and uniform in character. The quality of the coal is, however, unfortunately uniformly poor; the evaporative power ranging from 8 and less to a maximum of 11.25. The coal does not thus come up to the standard required by the railways and gold mines. The total coal reserves of the Orange Free State fields are probably considerably in excess of 100000000000 tons.

There are two working coalfields in the area, namely, the Cornelia-Clydesdale fields south of Vereeniging, and the Vierfontein fields south-east of Klerksdorp. The total proved and unproved coal in the former area is estimated at 11458000000 short tons with an evaporative power of from 8 to 11. Those of the latter area are estimated at 729000000 tons with an evaporative power ranging from 9 to 10.

C. The Coalfields of Natal and Zululand.

These are of considerable extent and second in importance only to those of the Transvaal. The seams are on the whole thinner than the Transvaal seams. A striking feature of certain sections of the fields is the extent to which the Coal Measures have been invaded by dykes and sills of dolerite. These have often changed the bituminous coal into more or less anthracitic coal or into impure coke. At the same time the gas given off has accumulated so as to convert many of the pits into fiery mines which have to be worked with safety lamps. Four main coal bearing areas may be distinguished, namely.

1. The Klip River or Main Line Coalfield. This is the most extensive extending from Elandslaagte to Newcastle. It has a length of 53 miles (85 km) and a width of 25 miles (40 km). There are two commercially valuable seams known as the "top" and "bottom", which are fairly persistent throughout the area. They are usually from 3 to 5 feet (0.9 to 1.5 m) thick (extremes 2 ft. [0.61 m] and 10 ft [3.05 m]) and from 5 to 6 feet (1.5 to 1.8 m) apart (extremes a few inches and 50 feet = 15 m).

The evaporative power of the coals from the central portion of the field varies from 13.44 to 15.15. They are high grade steam coales, the best found in South Africa, and are in great demand for the bunkering trade.

One colliery, Dewars Anthracite, situated east of Dundee, produces a high grade anthracite.

The gross reserves of the Klip River fields, in seams over 2 feet (61 cm), are estimated by Wybergh to be:

proved . . . . . . 443202000 short tons (6 feet [1.8 m] of coal);
estimated . . . . 777345000 short tons (6 feet 2 in. [1.88 m] of coal);
undetermined . . . 918498000 tons (3 feet 5 in. [1.04 m] of coal);
total . . . . . . 2139045000 short tons.

Most of this, however, is coal inferior in quality to that at present being mined. The reserves of high grade coal are relatively small and will, it is believed, be exhausted within 40 years at the present rate of output, namely, about 2300000 tons per annum.

2. The Vryheid Coalfield. This area, as Wybergh has pointed out, is not a continuous coalfield but the remains of one. It consists of a number of detached coal-bearing areas that obviously at one time formed a coalfield, continuous with that of the Utrecht District, of which the greater part has been removed by denudation. The mature dissection of the area has had only one advantageous result, and that is, that at many localities the workable seams outcrop high up on the sides of hills and are thus easily accessible to adit mining.

There are four seams, known as the "Alfred", "Gus", "Dundas" and "Coking", averaging 4 feet (1.2 m), 4 feet (1.2 m), 5 ½ feet (1.65 m) and 2 ½ feet (0.75 m) thick respectively. The "Gus" seam is the most important. The coal of this field is on the whole of excellent quality, being low in ash and sulphur. The evaporative power varies from 13.35 to 14.34. A good deal of the coal is a highgrade coking coal, the coke made at the Bernica Colliery being recognised as the best South African coke.

The Vryheid field is responsible at the present time for 55 per cent. of the total Natal output. The proved reserves are: 277102000 short tons, and the estimated reserves 294398000 short tons, a total of 570500000 short tons.

3. The Utrecht Coalfied. This comprises all the coal-bearing ground within the Magisterial district of Utrecht of which it constitutes a large portion. Near Paulpietersburg there are four seams identical with those of the Vryheid Coalfield. They aggregate from 10 to 11 feet (3.05 to 3.35 m) of coal. The total thickness of the coal at present being worked is 7 feet 3 in. (2.21 m). The coal varies from bituminous to semi-bituminous, and is on the whole of excellent quality. The evaporative power averages 13.62. Unfortunately the ash of some of the coal has a low fusibility causing clinkering. The reserves are as follows, proved coal 94098000 tons; estimated coal 256240000 tons. Both estimates are of coal containing over 16 per cent. of volatiles.

4. The Zululand Coalfied. There are extensive coal-bearing areas in Zululand, but so little systematic work has been done in that territory that this field is at present an unknown quantity. A colliery was started some years ago at Somkele about 20 miles (32 km) from the coast, but the coal proved too anthracitic and dirty to be worth working. It should be stated that the Zululand coalfield is continous with the southern part of the Lebombo Coalfield previously referred to.

In the Cape Province workable seams of coal are confined to the Molteno Beds (Rhaetic) of the Stormberg Series, and thus occur much higher up in the Karroo Succession than the Transvaal and Natal seams. The coals appear at intervals along a belt of country extending from Aliwal North to Molteno, and then eastward through the Transkei toward Natal[1].

They occur on three well-defined horizons known as the Indwe, Guba and Molteno Seams. Of these the first and third are the most important. The seams are invariably thin, the thickness of a single layer of coal rarely exceeding 2 feet (0.61 m). At the same time the coal is much interlaminated with shale and is high in ash and poor in volatile matter. It is in consequence unable to compete with the better and cheaper coals produced in the Transvaal and Natal except in a limited area adjacent to the mines. The most important colliery is situated at Indwe.

The Coal Measures are intruded by numerous dykes and sills of dolerite which have had a very injurious effect on the coal.

The available reserve is considerable, but too little work has been done away from the outcrops to enable even an approximate estimate to be framed.

[1] Rogers, A. W. and du Toit, A. L. Geology of the Cape Colony.

Table of proximate analyses of South African Coals.

Field.	Colliery.	Moisture	Volatile Matter	Fixed Carbon.	Ash.	Sulphur.	Evaporative Value[1].
Witbank (Transvaal)	Witbank	0.94	27.04	59.96	13.82	1.24	13.01
Ermelo-Carolina (Transvaal)	Breyten	2.75	30.42	50.87	15.96	1.00	12.03
Springs (Transvaal)	Brakpan	4.59	21.76	52.50	21.5	2.00	9.3
Klip River (Natal)	Natal Navigation	0.90	21.78	69.91	7.41	1.30	14.0 to 15.15
Vryheid (Natal)	Bernica	0.70	20.46	68.28	9.90	0.43	14.5
Vereeniging (Orange Free State)	Cornelia	5.40	22.48	50.80	19.95	1.26	9.6
CapeProvince	Molteno	1.13	10.31	60.89	28.8	0.76	n. d.

Statistics of Production.

The coal output of the Union of South Africa during 1925 was 13007141 short tons valued at £ 3880442. The production of the individual provinces was as follows:

Province.	Tons Sold.	Value at Pits Mouth. Sterling.	Value per Ton. s. d.
Transvaal	7399378	1863882	5. 0.46
Orange Free State	974324	271276	5. 6.82
Natal	4627831	1741242	7. 6.30
Cape Province	5608	4042	14. 4.98
Total	13007141	3880402	5. 10.6

Lignite.

Beds of impure lignite occur in the Uitenhage beds (Neocomian) in the south coast region of the Cape Province. They are apparently of very limited extent and of no economic importance.

In the Knysna district beds of lignite up to 8 feet (2.44 m) thick occur in some unconsolidated sandy deposits of probably Tertiary age. They were first opened up in 1908. Since then no further developments have taken place, and it is to be concluded therefore that they did not prove worthy of exploitation.

There is also a deposit of lignite on the west coast of the Cape Province in the Van Rhynsdorp division about 20 miles north of the mouth of the Olifants River.

Corundum.

The Transvaal possesses the richest and most extensive corundum fields in the world[2]. They cover an area of 2000 square miles (5180 qkm) in the northern and

[1] Pounds of water per pound of coal, to convert into gramme Calories multiply by 536.76.

[2] cf. Hall, A. L. "Corundum in the Northern and Eastern Transvaal", Memoir No. 15, Geol. Survey Un. of S. Africa, 1920.

Wagner, P. A. "The Corundum of the Zoutpansberg Fields and its Matrix", Trans. Geol. S. Africa, 1918, pp. 37—42.

north-eastern parts of the Province, and embrace two distinct tracts of country. These are (a) a Northern tract lying in the Zoutpansberg district athwart the Pietersburg-Messina railway, the industry being centred about Bandolier Kop and Mara; and (b) an Eastern tract situated in the "Low" country south and east of Leydsdorp, and practically coextensive with the Olifants River mica fields to be presently referred to.

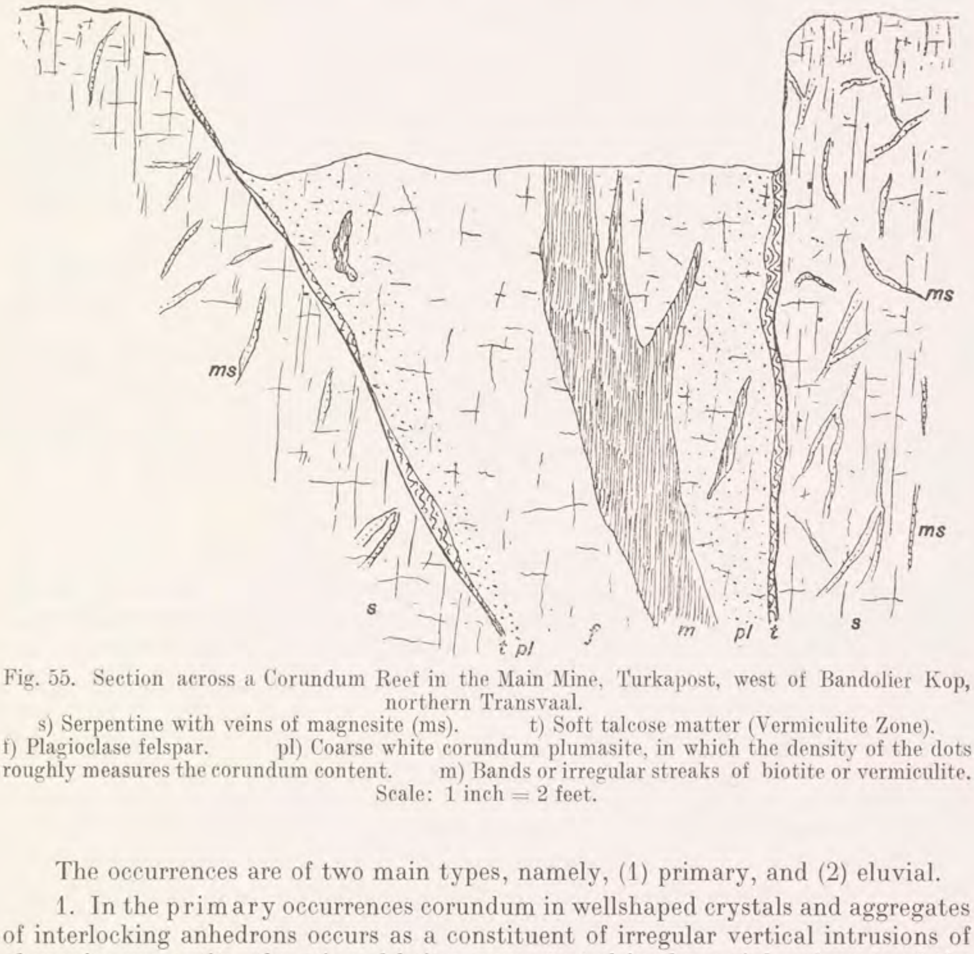

Fig. 55. Section across a Corundum Reef in the Main Mine, Turkapost, west of Bandolier Kop, northern Transvaal.
s) Serpentine with veins of magnesite (ms). t) Soft talcose matter (Vermiculite Zone).
f) Plagioclase felspar. pl) Coarse white corundum plumasite, in which the density of the dots roughly measures the corundum content. m) Bands or irregular streaks of biotite or vermiculite.
Scale: 1 inch = 2 feet.

The occurrences are of two main types, namely, (1) primary, and (2) eluvial.

1. In the primary occurrences corundum in wellshaped crystals and aggregates of interlocking anhedrons occurs as a constituent of irregular vertical intrusions of plumasite pegmatite, the mineral being concentrated in the peripheral parts of the intrusions. The bodies of plumasite pegmatite are up to 12 feet (3.66 m) thick and carry from 12 to 60 per cent. of corundum. They are intrusive in peridotites, pyroxenites and basic schists, which are also invaded by gneiss-granite. Where a pegmatite body is followed from the basic rocks into the granite it ceases to bear corundum and becomes an ordinary quartz-felspar pegmatite. The ultrabasic rocks are altered along their contacts with the corundiferous pegmatites the commonest alteration product being talc. These facts led HALL to conclude that the corundum bearing rocks originated as pegmatitic solutions segregated from the granite-gneiss magma (see Fig. 55). The solutions as a result of reaction with the basic magnesian rocks with which they came into contact suffered desilication. This led to their becoming supersaturated with alumina that crystallised as corundum while at the same time

the liberated silica attacked the ultrabasic rocks forming talc, and certain other constituents, such as potassa, gave rise to the selvages of biotite that frequently encase the reefs.

In the Eastern area subsequent magmatic changes under pneumatolytic conditions resulted in many instances in the conversion of the original corundum-felspar rock (plumasite) into margarite-felspar rock for which HALL has proposed the name marundite.

2. The eluvial deposits consist of extensive, shallow, residual surface accumulations of corundum crystals ("crystal corundum") accompanied by scattered lumps of corundum-rich corundum felspar rock ("boulder corundum") derived from the disintegration of bodies of plumasite and marundite. They cover considerable areas, and have been the source of most of the corundum so far exported from South Africa. It is worth noting, however, that the "grain" corundum prepared by crushing and concentrating plumasite has been proved by tests carried out in the United States to be a much better abrasive than the crushed "crystal" corundum.

Small quantities of corundum have also been recovered at intervals from the neighbourhood of Steinkopf in Namaqualand, where the mineral occurs as a constituent of corundum-gneiss.

The commanding position of the Union in the corundum industry is indicated by the following figures giving the world's output of the mineral during 1924: Union of South Africa . . . 1668 long tons; Madagascar . . . 145 long tons; Southern Rhodesia . . . 37 long tons. The output of the Union for 1925 was 1832 tons valued at £ 13229.

Diamonds.

Notwithstanding recent discoveries elsewhere; the Union of South Africa continues to be the leading producer not only "mine" but of alluvial diamonds, having been responsible during 1926 for about 75 per cent. by value of the world's production of these the most sought after of all precious stones. If the output of her mandated territory South-West Africa were to be included the percentage would have to be increased to about 84 per cent.

Production since 1867, when the first find was made, amounts to roughly 42 tons valued at over £ 270000000, and this notwithstanding, it is safe to assert that even if no new discoveries are made — which is unthinkable — the assured reserves are sufficient to keep the world supplied for the next hundred years or more.

The Union output for 1926 amounted to 3327854 carats[1] valued at £ 10683597. Of this total the mines or kimberlite occurrences contributed 2439637 carats valued at £ 6699916, and the alluvial fields 808329 carats valued at £ 3983681.

Until quite recently the bulk of the production came from the kimberlite occurrences. Since the beginning of 1927, however, the alluvial output has, as a result of the very important discoveries in the Lichtenburg district of the Transvaal, assumed enormous proportions. Its value is now roughly equal to that of the mines, and, in view of the big prospective output from the deposits on the Namaqualand coast is likely to remain at that for a year or two.

Kimberlite Occurrences. While pipes and dykes of kimberlite are, as we have seen, scattered over an enormous area of the plateau tract of Southern Africa, the proved workable occurrences are confined to a fairly well defined Diamond Belt extending in a north-easterly direction from Jagersfontein in the Orange Free State to the Premier Mine in the Transvaal, a distance of 350 miles (563 km) (see

[1] The international carat is the equivalent of 200 milligrames.

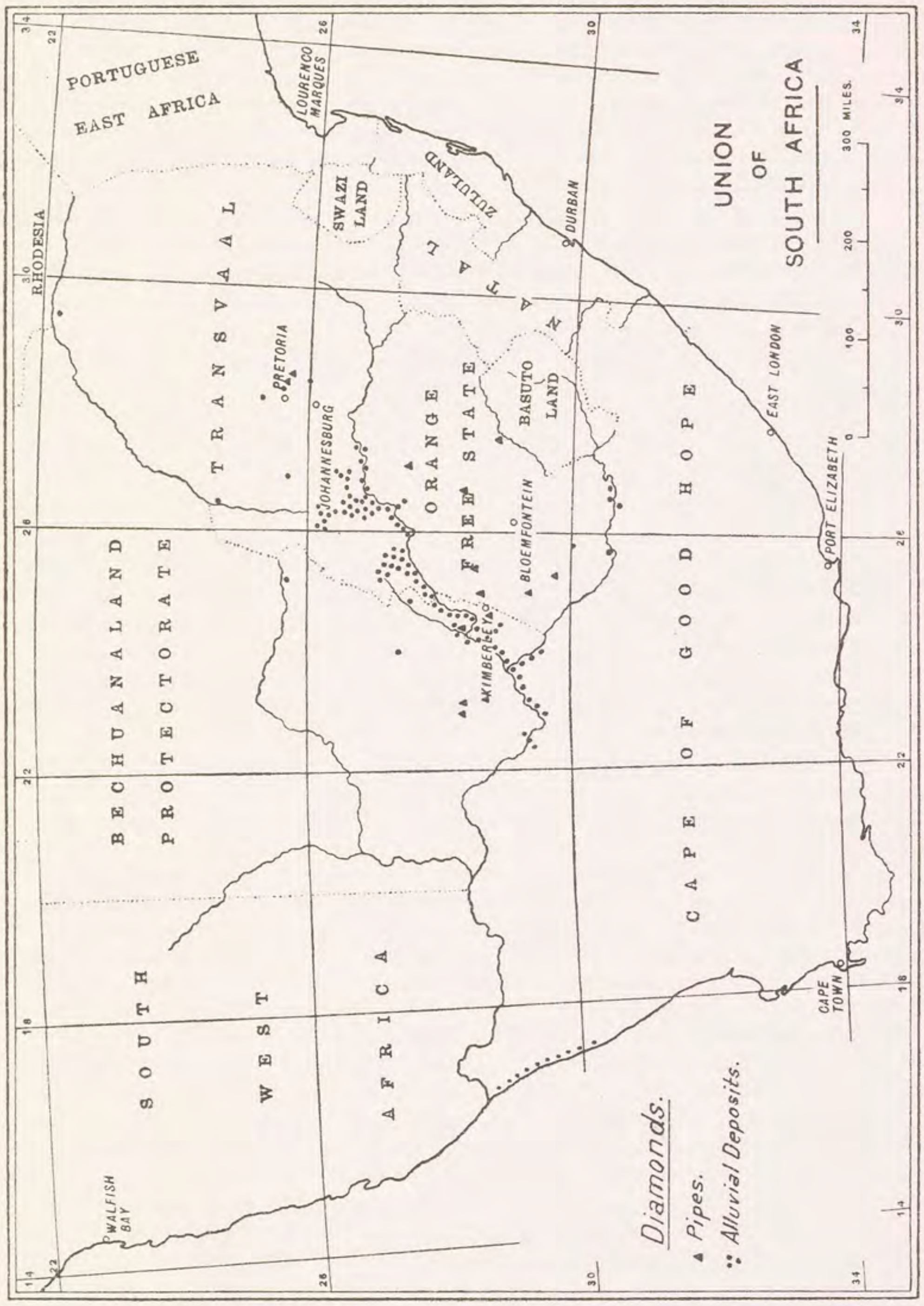

Fig. 56. Outline map showing the distribution of Diamond pipes and Alluvial deposits.

Fig. 56). The Premier is also the most easterly of the pipes so far worked. The West End and Postmas pipes near Postmasburg are the most westerly. Of some 150 pipes so far discovered only about 25 have been found to be worthy of exploitation, and of them seven have been responsible for much the greater part of the huge output previously stated. The seven are: the Kimberley, De Beers, Du Toit's Pan, Bultfontein and Wesselton situated in and in the neighbourhood of Kimberley; the Premier near Pretoria and the Jagersfontein at Jagersfontein. The Kimberley Mine, by far the richest ever discovered, was finally abandoned in 1921, the workings at that date having attained a depth of 3520 feet (1073 m).

A number of kimberlite dykes have also been successfully worked. One such, connected with the New Elands pipe in the Orange Free State, is being mined at a depth of 500 feet (152 m). It averages 20 feet (6.1 m) in width.

The main features of the kimberlite occurrences have already been dealt with (page 151) and need not here be enlarged upon.

Alluvial Deposits. Alluvial diamonds have an extraordinarily wide distribution in the basins of the Orange, Vaal and Harts rivers. New discoveries are continually adding to the already enormous area of the known fields, the latest being in the Lichtenburg, Ventersdorp and Potchefstroom districts of the Transvaal, in the Taungs district of Griqualand West and at the mouth of the Orange River.

Patches of diamond-bearing gravel also occur along the Molopo River at Pitsani and other localities; in the valley of the Limpopo and its tributary the Marico; and one of the tributaries of the Pienaars River, draining the area in which the Premier Mine is situated, has long been the scene of diamond diggings on a considerable scale.

Finally reference may be made to the interesting deposits at Mahura Muthla on the Kaap Plateau.

The most productive fields are those of the Lichtenburg, Ventersdorp, Potchefstroom, Bloemhof and Wolmaranstad districts of the Transvaal and along the Vaal River in Griqualand West.

The Lichtenburg district deposits discovered during 1926 are of phenomenal richness and are the most important alluvial occurrences so far found in the Union. They are at present producing diamonds at the rate of over £ 5500000 per annum. The deposits are situated 15 miles (24 km) to the north of the town of Lichtenburg and take form of "runs" and big irregular patches of rather coarse gravel, for the most part occupying great "sinks" in the dolomite of the Transvaal System. The gravels are up to 100 feet (30.5 m) in thickness. They were clearly laid down by an ancient river that traversed the area from north-east to south-west. It was probably part of the Proto-Molopo. The richest deposits are on the farms Welverdiend, No. 248, Ruigtelaagte, No. 205, Uitgevonden No. 99, which is subdivided into Elandsputte and Treasure Trove, Grasfontein No. 240, Hendriksdal No. 219 and La Reys Stryd No. 220. On Grasfontein diggers have made fortunes out of single claims measuring 45 by 45 feet (13,7 by 13,7 m).

The diamonds, which are accompanied by rolled pebbles of carnelian, agate, corundum, quartz, goethite and tourmaline rock, apparently come from the north-east, but their precise source is at present unknown.

At the present time (April, 1927) the Lichtenburg Diggings support a population of 50000 Europeans and 90000 natives. The diamonds of the Lichtenburg fields are smaller and inferior in quality to those found on the other alluvial fields of the Union with the exception of those of the Pretoria district. The average value per carat is only about 55 shillings. How this compares with the value of the stones produced on some of the other diggings may be seen from the following table.

Field.	Value per Carat. s. d.
Hopetown	238. 2.
Prieska	235. 3.
Kimberley	218. 9.
Western Transvaal	86. 4.
Lichtenburg	55. 0.
Pretoria District	41. 5.

Deposits along the North-West Coast of the Cape Province. Within the past 18 months it has been established that a vast alluvial diamond field extends along the north-west coast of the Cape Province from the mouth of the Orange River as far at least as the south bank of the Groen River, a distance of over 200 miles (322 km). The deposits are for the most part deeply buried by sand, surface limestone and later gravels. It is improbable therefore that more than a small part of the field will ever be worked. The diamonds are found in marine gravels occupying wavecut terraces lying at elevations of from 20 to 210 feet (6.1 to 64.1 m) above sea-level. The greatest distance from the present shoreline at which they have been found so far is 3 miles (4.8 km). It is probable, however, from the configuration of the littoral that they will be found much farther inland.

The most important deposit so far found is situated three quarters of a mile (1.2 km) south of the Orange River and about 1 ½ miles (2.4 km) from the coast near Alexander Bay. Here a narrow strip of coarse gravel occupying what appears to be a storm beach, lying from 110 to 135 feet (33.5 to 41 m) above sea level, has been proved to be very rich in diamonds of exquisite quality; the biggest stone so far found weighs 81 carats. The diamonds have in part the character of mine stones. They were probably brought down from Griqualand West and the Orange Free State by the Orange and its tributaries and carried to their present resting place by waves and currents. It should be stated that there is a southward inshore current along this part of the coast that carries trees and drift-wood as far as Port Nolloth.

Fluorspar.

The Union of South Africa has in recent years become an important producer of fluorspar. The mineral is derived mainly from the Marico district of the Transvaal where it occurs in pipe-shaped and irregular replacement deposits, in the Dolomite Series of the Transvaal System. These are very closely related to the zinc and lead deposits of that area, to which reference has already been made.

The most important deposit is situated on the farm Oog van Malmani No. 101, about 15 miles (24 km) south of Zeerust. It is a funnel-shaped pipe in somewhat disturbed dolomite and chert. It measured 120 x 120 feet (36.6 x 36.6 m) at the surface; at 40 feet (12 m) the dimensions had decreased to 80 x 60 feet (24.4 x 18.3 m), and at a depth of 85 feet (26 m) it passes downward into a number of irregular fluorspar veins. The pipe-shaped portion of the deposit is occupied in its peripheral part by greyish and purple fluorspar enclosing isolated patches of galena, zincblende, pyrrhotite and calcite. The interior was occupied by pure colourless spar some of which was considered good enough for optical purposes and realised 10 shillings per ounce in London. The ordinary "run of mine" fluorspar is also of exceptional purity, some of the shipments having averaged 99.4 per cent. of CaF_2. The dolomite surrounding the pipe is much altered and is unusually rich in talc, which appears here to take the place of the tremolite surrounding the Witkop zinc pipe.

There are less important fluorspar deposits in the same area on the farms Buffelshoek, No. 284, Naauwpoort, No. 102, and Strydfontein, No. 267.

At the present time fairly considerable quantities of fluorspar are also being recovered from flat-dipping veins of pegmatite in Bushveld Granite south-west of Warmbaths in the Transvaal.

Gannister.

An important deposit of gannister is associated with the fire-clays occurring near Boksburg in the Transvaal.

Graphite.

Only one workable deposit of graphite has so far been discovered in South Africa. This is situated on the farm Goedehoop, No. 223, 20 miles (32 km) east of Groot Spelonken Siding in the Zoutpansberg District of the Transvaal[1]. It takes the form of a lens with an average thickness of about 10 feet (3.05 m), formed mainly by massive graphite which is interspersed with patches and traversed by veinlets of flake- and columnar- graphite. The footwall of the deposit is formed by decomposed pyroxenite, and the hanging-wall by schistose quartzite, striking east and west and dipping at 55 degrees to the south. The graphite lens conforms in dip and strike to the quartzite.

An average of about 3 tons per month of dressed graphite is produced from this deposit.

Gypsum.

Gypsum, used mainly as a retarder in Portland cement and also to some extent for water purification and manufacture of plaster of Paris, is quarried in fairly considerable quantities in the Union.

The principal deposits are situated in Griqualand West and the adjacent north-western portion of the Orange Free State. Here the mineral occurs at many localities in seams and beds of loose crystals, or in irregular masses in superficial deposits of clay, silt and sand probably occupying old pans and "vleis", the gypsum having evidently been deposited from surface waters. The seams are up to 6 feet (1.8 m) in thickness, and there are sometimes several of them above one another. The chief occurrences so far worked are on the farms Gannavlakte near Windsorton Rietpan near Riverton Road in Griqualand West, and Vrede 16 miles south-east of Boshof in the Orange Free State. There is also a considerable gypsum deposit at 'Ngobevu in Natal, and some of the salt pans in the Calvinia Division of the Cape Province and near Port Nolloth also contain gypsum.

Kieselguhr.

Kieselguhr has a wide distribution in the Ermelo district of the Transvaal, and in Griqualand West, Gordonia and the Bechuanaland Protectorate. In the Ermelo District it occurs as a rule as a black peaty deposit occupying the beds of small fresh-water marshes. The most important deposit is on the farm Bankplaats, No. 87, situated 12 miles north-west of Sheepmoor Siding. It has been worked at different times, white kieselguhr of great purity being obtained by calcining the peaty matter.

In Griqualand West and the other areas named kieselguhr occurs in shallow pans in association with calcareous tufa.

Limestone and Dolomite.

The Union is, on the whole, rather poorly off in limestone suitable for industrial purposes, but has vast resources of pure dolomite. This rock is being utilised to a

[1] Wagner, P. A. S. A. Journal of Industries, May, 1918.

limited extent for the production of what is known as "blue lime", but is to be used on a large scale as a flux in the iron works which it is proposed to erect at Pretoria.

The limestones proper fall into two main categories[1], namely

1. Primary limestones;
2. Secondary limestones.

1. Primary limestones.

The most important deposits under this heading are the marbles on the farms Marble Hall, No. 248, and Scherp Arabie No. 367, in the north-eastern part of the Pretoria District; a broad belt of pure crystalline limestone on the farm Inkom, No. 1727 in the northern part of the Zoutpansberg district, Transvaal; occurrences of crystalline limestone belonging to the Malmesbury Series in the Robertson, Piquetberg and Van Rhynsdorp divisions of the Cape Province; and near Hankey and Patentie in the Humansdorp division of the same province.

With the exception of the deposits near Piquetberg, which are being worked by the Cape Portland Cement Company, all these occurrences are unfortunately too inaccessible at the present time to be of commercial value.

2. Secondary limestones

have a very wide distribution in South Africa and are very largely used for the production of lime and cement. They are of four main types, namely

a) Cliff Travertine and allied varieties;
b) Vlei limestones;
c) Surface limestone proper;
d) Cave limestone.

a) Cliff Travertine. The principal deposits of this type of limestone are situated along the eastern escarpment of the Kaap Plateau in Bechuanaland. That at Buxton, 7 miles (9.7 km) south-east of Taungs, has been worked for some years and is of great magnitude. According to WYBERG and YOUNG[2] it consists mainly of calcareous tufa, of the "cliff travertine" variety, occupying an ancient river channel where it widened out on leaving the Kaap Plateau and entered the broad valley of the Harts River. The limestone is of exceptional purity. About 6 miles to the south is another great deposit of "cliff travertine" following the edge of the Kaap Plateau.

b) Vlei limestone. This usually consists of fine white or grey chalky material enclosing porous lumps and masses of tufa. It has clearly resulted from the precipitation of calcium carbonate from more or less stagnant or slowly moving water by swampy vegetation. There are important deposits of this type of limestone on Paardevallei and adjoining farms in the Marico District of the Transvaal.

c) Surface Limestone Proper. This consists of solid sheets or layers composed of nodular concretions of calcium carbonate of varying degrees of purity formed by the slow rise to the surface by capillary action and its evaporation there of lime bearing water. The sheets are up to 100 feet (30.5 m) thick. The limestone is sometimes pure but generally contains a good deal of silica in the form of sand. Thus the surface limestone quarried by the Pretoria Portland Cement Company 5 miles (8 km) east-north-east of Pienaars River in the Transvaal contains up to 15 per cent. of silica.

There are very extensive deposits of surface limestone in the central and western Transvaal and in the Winburg and adjoining districts of the Orange Free State.

[1] WYBERGH, W. J. "The Limestone Resources of the Union". 2 Volumes, Geol. Surv. Un. of S. Africa, Memoir No. 11.

[2] Trans. Geol. Soc. S. Africa, 1925, p. 55.

d) Cave Limestone. This consists of stalactites and stalagmites or irregular banded sheets composed mostly of acicular crystals of aragonite. The deposits are as a rule of limited extent, but yield lime of exceptional purity. Such cave limestone is worked at Makapans Gat north of Potgietersrust in the Transvaal.

In conclusion brief reference may be made to an important occurrence of limestone situated at Uitloop north of Potgietersrust, which has resulted from the dedolomitisation under rather peculiar circumstances of the dolomite of the Transvaal System[1].

Magnesite.

A number of occurrences of this mineral have been located in the Barberton District of the Transvaal, in the basic and ultrabasic rocks of the Jamestown Series. They are being worked at the Budd and Althorpe Mines situated near Magnesite Siding on the Pretoria-Delagoa Bay railway. At both mines magnesite of the "dense" variety forms an anastomosing veins up to 3 feet (0.91 m) in thickness in serpentine. It is of great purity and is used for the manufacture of magnesite bricks. There are similar deposits east and north of Eureka Siding on the Barberton Railway.

There are also important occurrences of magnesite in the ultrabasic rocks of the norite zone of the Bushveld Complex in the Lydenburg, Pietersburg and Marico districts of the Transvaal. Some of this magnesite is pure, but some of it contains a good deal of calcium carbonate[2].

Mica.

Mica of excellent quality is found in the Leydsdorp division of the Pietersburg district of the Transvaal, where there is a well-defined mica belt from two to four miles wide extending in an east and west direction from the neighbourhood of Mica Siding to the Portuguese border. The most important deposits lie between the Mashishimala Hills and the Olifants River[3]. The mica occurs in great dykes and irregular masses of coarse-grained white pegmatite following the southern margin of the Palabora granite massif. The pegmatite bodies are up to several hundred yards in length and up to 60 feet (18 m) in width. The muscovite occurs in books exceptionally as much as 14 feet (4.28 m) across, and in irregular nests and pockets. As a rule the distribution of the mineral is quite irregular, but occassionally, as at the Godiva Mine, it follows more or less definite zones close to the contact of the pegmatite of the surrounding rocks. Such zones are comparable with ore shoots in mineral veins and point to the mica being of slightly later formation than the main mass of the pegmatite. The muscovite, speaking generally, has a pale-brownish tint, but a soft pale-green variety occurs near Malelane and at other localities in the southern part of the mica belt.

Muscovite of merchantable quality also occurs in Namaqualand, but no precise information is available regarding the deposits.

Mineral Paints.

Pure red and yellow ochre are quarried at Hazeldene situated 15 miles (24 km) east of Dundee in Natal, the mineral worked being an ochreous phase of a bed of iron ore occurring in the Coal Measure Series of the Karroo System at this locality.

Ochres and mineral paints are also worked at other localities in Natal.

Brown umber of good quality occurs in the dolomite north of Krugersdorp in the Transvaal.

[1] Young, R. B. Trans. Geol. Soc. S. A. 1916, p. 57.
[2] Wagner, P. A. S. A. Jl. Ind. Vol. I, pp. 570—578, 1918.
[3] Hall, A. L. "Mica in the Eastern Transvaal", Memoir No. 13, Geol. Surv. Un. of S. Africa.

Monazite.

Monazite in crystals and anhedrons up to 2 inches (5 cm) across is found in pegmatite veins in granite porphyry on the farm Hotenbeek No. 561, situated some 70 miles (113 km) north-east of Pretoria. The mineral unfortunately only contains about 1 per cent. of thorium oxide and has therefore no economic value.

Natural Gas.

Natural Gas has so far only been struck in considerable quantity on the farm Gruisfontein in the Heidelberg district of the Transvaal where it is encountered at a depth of 540 feet (165 m) below a sill of dolerite that acted as an impervious cover. CUNNINGHAM CRAIG[1] is of opinion that there may be other isolated reservoirs of gas in the area, and also considers that the Fauresmith District of the Orange Free State and the Folded Belt along the southern margin of the Karroo offer favourable conditions for the occurrence of gas.

Large volumes of pure carbon dioxide issue along a fault in Dwyka Tillite on the farms Huhenden, Lot 10 and Lot 7 in Alfred County, Natal[2]. The gas is collected and used for aerating mineral waters.

Nitrates.

In the Prieska and Hay districts of the Cape Province fairly pure saltpetre occurs as an incrustation, in veins and pockets and impregnating clayey ferruginous matter (a) on cliff faces, and particularly at the base of such cliffs, and (b) in caves and recesses and other places protected from rain, in scarped ranges of hills built of the banded ferruginous shales and jaspers of the Lower Griquatown Series[3].

The deposits are scattered over a considerable extent of country stretching from Griquatown to 20 miles (32 km) south-east of Prieska; the nitrate belt being coextensive with the outcrop of the rocks of the Lower Griquatown Series. The deposits owe their origin to a process of nitrification by bacterial action of the excrement of small mammals and birds, the potash having evidently been derived from the shales of the Griquatown Series which have been proved to contain appreciable amounts of potassa. Several attempts to work these deposits have failed, but small amounts of nitre are obtained by picking along the cliff faces.

Somewhat similar deposits of calcium nitrate are found on cliffs of dolomite east of Chuniespoort in the Pietersburg district of the Transvaal.

Of a totally different nature is the occurrence of nitrates below the Matsap Pan in the Hay district of Cape Province[4]. Here gritty layers intercalated with clay and shale underlying the Pan have been proved to be impregnated with the brine carrying sodium and magnesium sulphate and chloride and notable amounts of sodium nitrate. A process for separating the sodium nitrate by fractional crystallisation has been devised, but has not so far been applied on a practical scale.

Oil Shale.

True torbanite, consisting largely of minute "kerogen" bodies, is developed on several horizons in the Coal Measure Series (Middle Ecca) of the Karroo System, in the Bethal, Ermelo and Wakkerstroom districts of the Transvaal, and in the Utrecht and Dundee districts of Natal[5]. The torbanite beds are generally found underlying

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[1] "Report on the Petroleum Prospects in the Union of South Africa", Pretoria, 1914.
[2] YOUNG, R. B. Trans. Geol. Soc. S. Africa, 1923, p. 99.
[3] cf. FROOD, G. E. B. and HALL, A. L. Memoir No. 14. Geol. Surv. Un. of S. Africa, 1919.
[4] cf. ROGERS, A. W. S. A. Jl. Ind. Feb. 1922.
[5] TREVOR, T. G. "S. A. Jl. Ind. July 1923, and WAGNER, P. A. "Mineral Oil . . . Oil Shale", S. A. Jl. Ind. 1917, pp. 126—152.

or interbedded with thin seams of coal. They are unfortunately thin compared with beds of oil shale found in other parts of the world, their thickness ranging from 6 inches to 3 feet (15 cm to 90 cm). The torbanite yields from 20 to 100 gallons of oil per ton, and from 8 to 48 lbs. of ammonium sulphate.

The most promising deposits so far discovered are on the farms Mooifontein No. 287 situated in the Ermelo district 8 miles (13 km) north of Ermelo, and on the farm Kromhoek No. 76, Virginia No. 371, Goedgevonden No. 77, and Yzermyn No. 280 in the Wakkerstroom district.

Recently a seam of torbanite has been located near Greylingstad in the Heidelberg district of the Transvaal, on Herpsfontein No. 234 and adjoining farms.

Efforts are at present being made to raise capital to provide plant for working these several deposits.

A good deal of exploratory work has also been done on the carbonaceous oil-yielding shale occurring in the Stormberg Series in the Impendhle district of Natal. This yields up to 32 gallons of oil per ton[1].

Petroleum.

Although "shows" of naturally distilled oil occur at numerous localities in the area occupied by the rocks of the Karroo System, generally in or in the neighbourhood of intrusions of dolerite, and have led to a great deal of costly and useless prospecting there is only one tract of country in the Union that offers some, at any rate, of the requisite conditions for the accumulation of oil in commercial quantities. This is the Folded Belt along the southern margin of the Karroo, and the only evidence of the existence or former existence of oil in this belt is furnished by peculiar veins of pseudo-coal and pseudo-anthracite found along its northern margin in the Laingsburg, Beaufort West and Fraserburg districts of the Cape Province[2].

According to Dr. A. W. Rogers the testing of this belt would involve the putting down of a number of boreholes to a depth of not less than 6000 feet (1830 m), and in view of the uncertainty as to whether, even in the event of the veins above referred to having resulted from the autopolymerisation of oil derived from pools below the area in which they occur, any of these pools still contain oil and, if so, whether in paying quantities, the sinking of these very costly bores would, to say the least of it, be a highly speculative venture.

Phosphates.

There are extensive deposits of rock phosphate at Saldanha Bay on the west coast of the Cape Province[3]. The phosphate, an intimate mixture of aluminium and iron phosphate, has been formed mainly by the phosphatisation of granite and quartz porphyry detritus, and to a less extent by the phosphatisation of these rocks in situ. An attempt was made in 1918 to work these deposits on a big scale, but it was found that, while the surface crust was fairly rich, the average phosphoric oxide content was too low to admit of the conversion of the phosphate into fertiliser containing sufficient available phosphorus to enable it to compete with imported phosphates.

A small deposit of the more valuable calcium phosphate or phosphorite was found on the Hoetjes Bay Peninsula near Saldanha Bay.

[1] du Toit, A. L. "Report on the Oil Shales in Impendhle County, Natal". Pretoria, 1916.
[2] cf. Cunningham-Craig, loc. cit.; Rogers, A. W. "Report on the Prospect of Finding Oil in the Southern Karroo" Memoir N. 8, Geol. Surv. Un. of. S. Africa; Wagner, P. A. "Mineral Oil: Solid Bitumen, etc." S. A. Jl. Ind. Nov. 1917.
[3] du Toit, A. L. "Report on the Phosphates of Saldanha Bay", Memoir No. 10, Geol. Surv. Un. of. S. Africa, 1918.

Quite recently a promising deposit of phosphatised beach or dune sand has been discovered on Cravens Gift and adjoining farms near Mamre Road Station, on the line from Kalabas Kraal to Saldanha Bay. It is up to 7 feet (2.1 m) thick and analyses indicate up to 25.7 per cent. of P_2O_5, practically the whole of which is present as calcium phosphate.

Nodules and lenses of phosphate rock containing up to 28 per cent. of P_2O_5, combined with lime, occur in the Upper Dwyka shales near Matjesfontein and other localities in the Laingsburg division of the Cape Province[1]; also in the Upper Ecca shales in the Weenen area and elsewhere in Natal. They are unfortunately too small and too sparingly distributed to be worthy of exploitation.

At the present time there are being opened up on Spelonken Water No. 927, Schaapkraal No. 2622, and adjoining farms, situated 15 miles (24 km) east of Bandolier Kop in the Zoutpansberg district of the Transvaal, a series of apatite-bearing pegmatite veins[2]. They carry fluor-apatite in the form of big isolated crystals and in irregular pockets and steeply dipping bands and stringers evidently formed by pneumatolytic action at a slightly later date than the quartz and felspar which they accompany. The most promising occurrence so far opened up, situated on Spelonken Water No. 927, has an average width of 3 feet (0.9 m), and averages 18 per cent. of P_2O_5 over this width. Some of the other veins are also fairly rich, but the majority do not appear to be worth working.

Quartz.

A pure vein-quartz occurs in a big vein at the Modderfontein Dynamite Factory north-east of Johannesburg, and at many other localities in the areas occupied by the Old Granite. The Modderfontein quartz is being successfully employed for the manufacture of silica bricks.

Salt.

In the year 1924 there were produced in the Union of South Africa 77,569 short tons of salt valued at £ 111459. The whole of this output is derived from salt pans or from the brine found below the floor of such pans. The most important pans are situated in Griqualand West and the south-western Transvaal on Dwyka Tillite or Dwyka Shale, and the salt, which is evidently leached out of these rocks, is continually being replenished by a process of natural concentration. The pans are thus, as ROGERS and DU TOIT[3] have pointed out, among the most valuable assets of the country. The salt almost without exception contains notable amounts of sodium sulphate. This is removed in the process of refining the better grade of salt but is left in the ordinary salt.

Sands.

Sands suitable for making ordinary grades of glass-ware occur at Zandfontein north-west of Pretoria, at Wonderboom north of Pretoria, and Silverton and Pienaarspoort east of Pretoria; also at Vereeniging and the Tweefontein Colliery[4], in Zululand and at Philippi, on the Cape Flats near Cape Town.

Good moulding sand occur at many localities, notably at Vereeniging and Pretoria, and near Somerset West and Pretoria.

Sands suitable for building purposes and concrete have a wide distribution.

[1] ROGERS, A. W. "The Geology of the Country near Laingsburg", Explanation of Cape Sheet No. 5 (Laingsburg) Geol. Surv. Un. of S. Africa, 1915.

[2] HALL, A. L. Report (unpublished) on the workings of the South African Phosphate Exploration Syndicate near Bandolier Kop, Zoutpansberg District; also JANISCH, EDNA. Trans. Geol. Soc. S. Africa, 1926, pp. 100—135.

[3] "The Geology of Cape Colony", p. 438.

[4] WAGNER, P. A. S. A. Jl. Ind. 1919, p. 436.

Sillimanite.

Fairly pure sillimanite rock occurs at several localities in the northern part of the Zoutpansberg district, Transvaal. Samples of the rock are at present being tested with a view to ascertaining its suitability as a refractory.

Soda.

An average of about 250 tons per month of pure calcined sodium carbonate is produced at the Pretoria Salt Pan, previously referred to, by the South African Alkali, Limited; the soda is obtained from the brine pumped from the Gaylussite Layer underlying the floor of the pan. The brine contains an average of about 7 per cent. sodium carbonate and 15 per cent. of sodium chloride. Plant is being erected to recover the sodium chloride, which has hitherto been returned to the pan in the waste brine.

Spodumene.

Spodumene in crystals up to 4 inches (10 cm) across occurs in pegmatite veins at Jakhals Water in Namaqualand in association with tantalite and beryl. These are the only lithium-bearing pegmatites known in the Union.

Sulphur.

The pyritic concentrates of certain gold mines in the Sabie and Pilgrims Rest districts of the Transvaal constitute at the present time the only South African source of sulphur for the manufacture of sulphuric acid. The bulk of the concentrates come from the mines and the Sandstone Reef at the top of the Black Reef Series. The concentrates contain about 45 per cent. of sulphur, and up to 1 ounce of gold per ton. The sulphur is paid for at a fixed rate per ton, and the gold at full value minus a small percentage to cover extraction.

At Areachap, 23 miles (40.6 km) north-west of Upington, in the Cape Province, a series of big lenses of cupriferous pyrite occur along a zone of fissure striking east 30^0 south. Large amounts of pyrite are apparently available, but the occurrence is so inaccessible that the pyrite cannot compete on an economic basis with imported sulphur.

Talc.

Small amounts of talc have been produced for some years in the Barberton District[1] of the Transvaal, where there are extensive occurrences of both massive and foliated talc in the ancient serpentines and basic schists of the Jamestown Series. Recently a very important deposit has been opened up on the farm Strathmore near Malelane. This takes the form of a thick incline sheet or layer of foliated talc in a mass of serpentine. The talc is of exceptional quality, and arrangements are being made to export it on a big scale.

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[1] Hall, A. L. "On the Talc Deposits near Kaapmuiden in the Eastern Transvaal." Trans. Geol. Soc. S. Africa, 30, 1927.

V. Summary of Literature.

By

A. L. HALL.

Since the literature bearing on the geology of the Union of South Africa is fairly extensive and scattered through many different periodicals, books, memoirs, etc., official and private, it is not possible to do more in this summary, than to give the more important sources of information on the subject.

Official Publications.

a) National Surveys.

Systematic state-aided geological investigation is, or has been, carried on by the following Government institutions:—

1. The Geological Commission of the Cape of Good Hope. This organisation dates from 1896 and continued in force down to its amalgamation with the Geological Survey of the Transvaal into the Geological Survey of the Union of South Africa in 1910. Its publications consist of:—

a) Annual Reports, covering the operations during each calendar year. 1896—1911.
b) Geological Map of the Colony of the Cape of Good Hope. Scale 1 : 238 000. Seventeen Sheets are published. (See figure 57).
c) Index to the Annual Reports of the Geological Commission for the years 1896—1903, by E. H. L. Schwarz.

2. The State Geologist of the South African Republic, 1897—1900. The following publications were issued:—

a) "Rapport over het jaar 1897." Transvaal Gov. Reports (BB, 382—398). English Translation in Transactions, Geol. Soc. of S. Africa, 4, 1898—99.
b) "Rapport over het jaar 1898." Transvaal Gov. Reports, No. 16. 1899. English and German Translations, Pretoria, 1900.

3. The Geological Survey of Natal and Zululand. This institution ceased in 1908. The following was published:—

First Report, by W. Anderson, with contributions by R. Etheridge, jun. Maritzburg, 1902.
Second Report, by W. Anderson, with contributions by R. Etheridge, Jun. and A. C. Seward, London 1904.
Third Report and Final Report, by W. Anderson, with contributions by R. Etheridge, R. Broom, A. Smith Woodward, G. C. Crick and W. B. Scott. London, 1907.

4. The Geological Survey of the Transvaal. This organisation was established in 1903 and continued till 1910, when it became, together with the Geological Commission of the Cape of Good Hope, the present Geological Survey of the Union of South Africa. Its publications consist of:

a) Annual Reports, 1903—1909.
b) Memoirs Nos. 1—5, 1905—1910.
c) Report on a Reconnaissance of the North-Western Zoutpansberg District, by T. G. Trevor and E. T. Mellor, with an Introduction by H. Kynaston. Pretoria, 1908.
d) Geological Map of the Transvaal. Scale 1 : 148 700. Six Sheets have been issued, with explanations. See figure 57.

5. The Geological Survey of the Union of South Africa. The present organisation dates from 1910; its publications are:—

a) Annual Reports, 1910—1913; this issue ceased with the volume for 1913.
b) Memoirs.
c) Sheet Maps (with Explanations); see figure 57.
d) Special Publications.

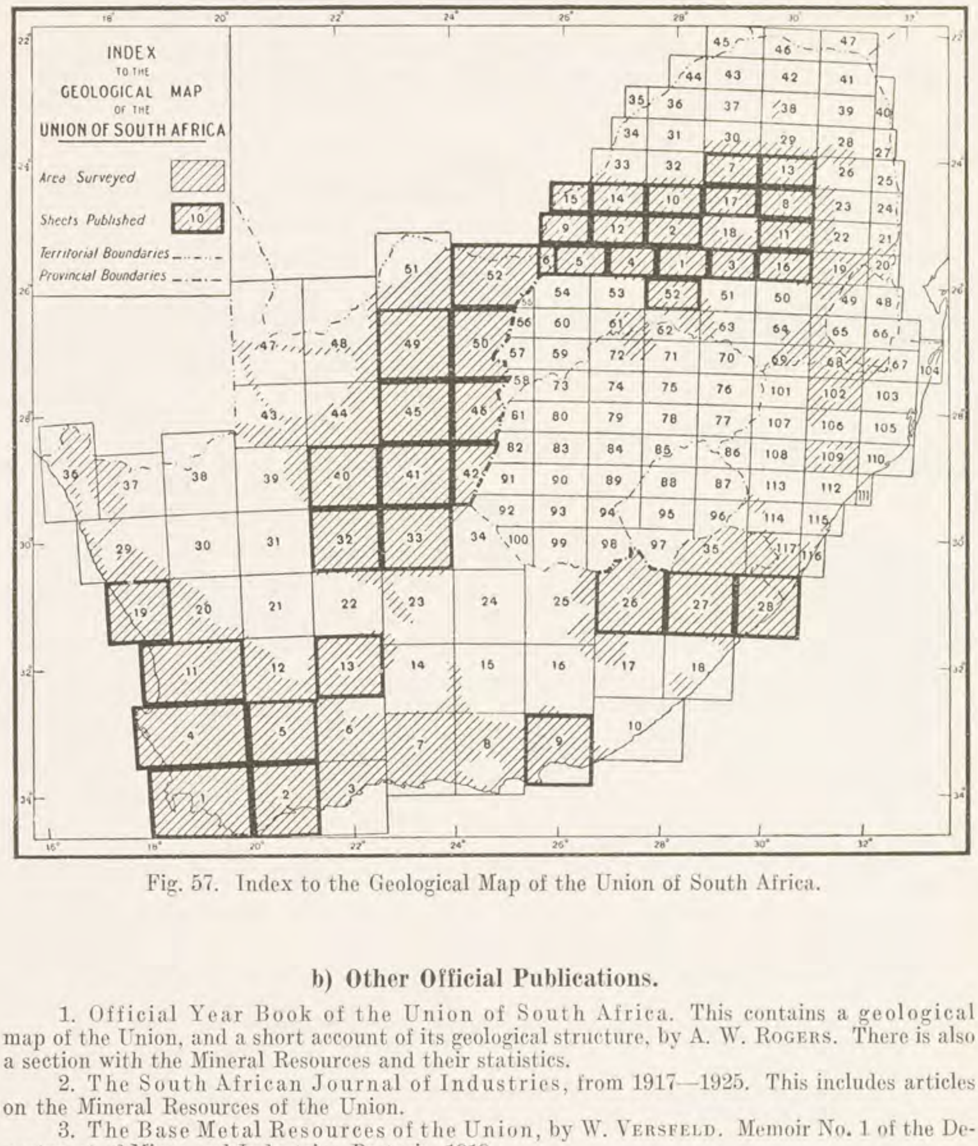

Fig. 57. Index to the Geological Map of the Union of South Africa.

b) Other Official Publications.

1. Official Year Book of the Union of South Africa. This contains a geological map of the Union, and a short account of its geological structure, by A. W. Rogers. There is also a section with the Mineral Resources and their statistics.

2. The South African Journal of Industries, from 1917—1925. This includes articles on the Mineral Resources of the Union.

3. The Base Metal Resources of the Union, by W. Versfeld. Memoir No. 1 of the Department of Mines and Industries, Pretoria, 1919.

Figure 57 shows the sheet maps published, and additional areas surveyed.

Publications of Museums.

Annals of the Durban Museum, edited by the Curator. Printed by J. Singleton and Son, Durban, for the Durban Museum.

Annals of the Natal Museum, edited by the Director. London, Adlard and Son and West Newman.

Annals of the South African Museum, printed for the Trustees of the South African Museum. Volumes 4, 7, 12, and 22 contain palaeontological papers published in conjunction with the Geological Survey.

Annals of the Transvaal Museum, Pretoria.

Records of the Albany Museum, printed for the Committee of the Albany Museum by Slater and Co., Grahamstown.

Publications of Scientific Societies, etc.

1. The Journal of the Chemical, Metallurgical and Mining Society, Johannesburg.
2. The South African Mining and Engineering Journal, Johannesburg; this was formerly known as the South African Mining Journal.
3. The South African Journal of Science, Johannesburg.
4. The Transactions of the Geological Society of South Africa, Johannesburg. Annual volumes beginning with Vol. I, 1895.
5. The Transactions of the Royal Society of South Africa (formerly known as the South African Philosophical Society).

Books.

1. Hatch, F. H. and Corstorphine, G. S. "The Geology of South Africa." London, 1909, Second Edition.
2. Oxford Survey of the British Empire. Vol. 2. Africa. Oxford, 1914—contains a section "Physical Geography and Geology" by A. W. Rogers.
3. Schwarz, E. H. L. "South African Geology." London, 1912.
4. Rogers, A. W. and Toit, A. L. du—"An Introduction to the Geology of Cape Colony". London, Second Edition, 1909.
5. Toit, A. L. du—"Physical Geography for South African Schools." Cambridge, 1912.
6. Toit, A. L. du—"The Geology of South Africa". Edinb. 1926.
7. Krenkel, E. "Geologie Afrikas". Zweiter Teil. Berlin 1928.

Bibliographies.

1. Hall, A. L. "A Bibliography of South African Geology to the end of 1920." Author's Index. Geological Survey Memoir No. 20. Pretoria, 1922.
2. Hall, A. L. "A Subject Index to the Literature on the Geology and Mineral Resources of South Africa." Geological Survey Memoir No. 22. Pretoria, 1924; includes a supplement to the bibliography.
3. Hall, A. L. "A Bibliography of South African Geology for the years 1921 to 1925 (inclusive). Authors Index. Geol. Surv. Mem. No. 25, Pretoria, 1927.
4. Hatch, F. H. and Corstorphine, G. S. "The Geology of South Africa"—includes a bibliography of the more important papers down to 1908.
5. Wilman, M. "Catalogue of Printed Books, Maps, etc. on South African Geology." Trans. S. African Philos. Society, 1904.

List of Illustrations.

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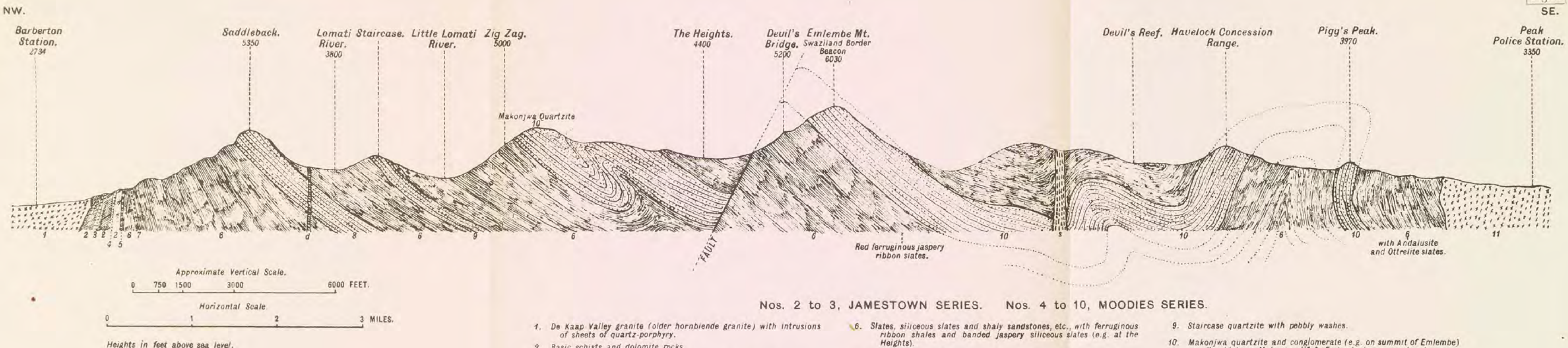
Fig. 6



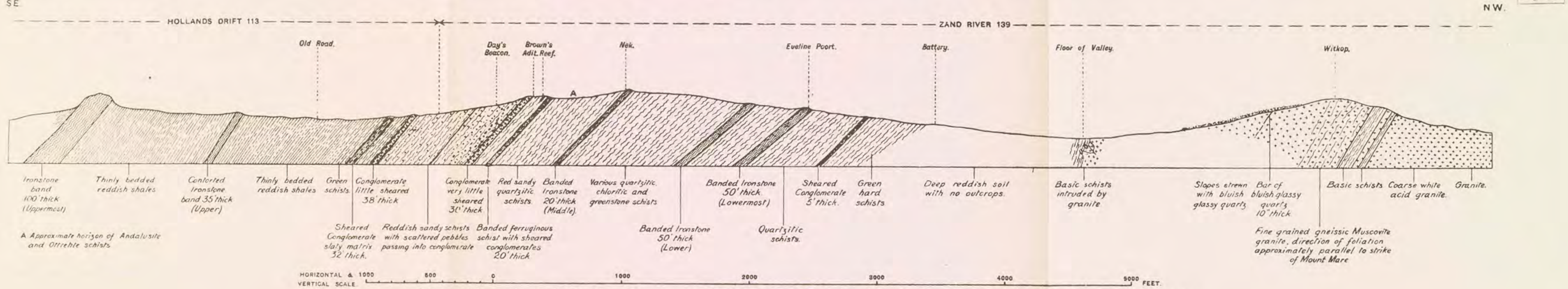
Nos. 2 to 3, JAMESTOWN SERIES. Nos. 4 to 10, MOODIES SERIES.

1. *De Kaap Valley granite (older hornblende granite) with intrusions of sheets of quartz-porphyry.*
2. *Basic schists and dolomite rocks.*
3. *Thin metamorphosed quartzite (at entrance to Rimers Creek).*
4. *Thinly bedded dark quartzite (Ivy or Baviaanskop quartzite?)*
5. *Dolomite conglomerate (up Rimers Creek).*
6. *Slates, siliceous slates and shaly sandstones, etc., with ferruginous ribbon shales and banded jaspery siliceous slates (e.g. at the Heights).*
7. *Narrow banded chert (Ulundi Bar?).*
8. *Saddleback quartzite and conglomerate. (d) Basic dyke.*
9. *Staircase quartzite with pebbly washes.*
10. *Makonjwa quartzite and conglomerate (e.g. on summit of Emlembe) =Kamhlubana-Makonjwa-Ufafa-Emlembe-Ingwenya band. (s) Serpentinous intrusion*
11. *Older biotite granite.*

N. B.—The tectonic features of this section agree in principle with those seen along the Ufafa section in the east (compare figure 10), and along the Ingwenya Section in the south (compare figure 9).

Composite Section across the Barberton Mountain Land from Barberton to Northern Swaziland.

Fig. 12



Section across Mount Maré through Eveline Poort near the eastern end of the Range. Pietersburg District, Transvaal Province.

Carl Winters Universitätsbuchhandlung, Heidelberg.

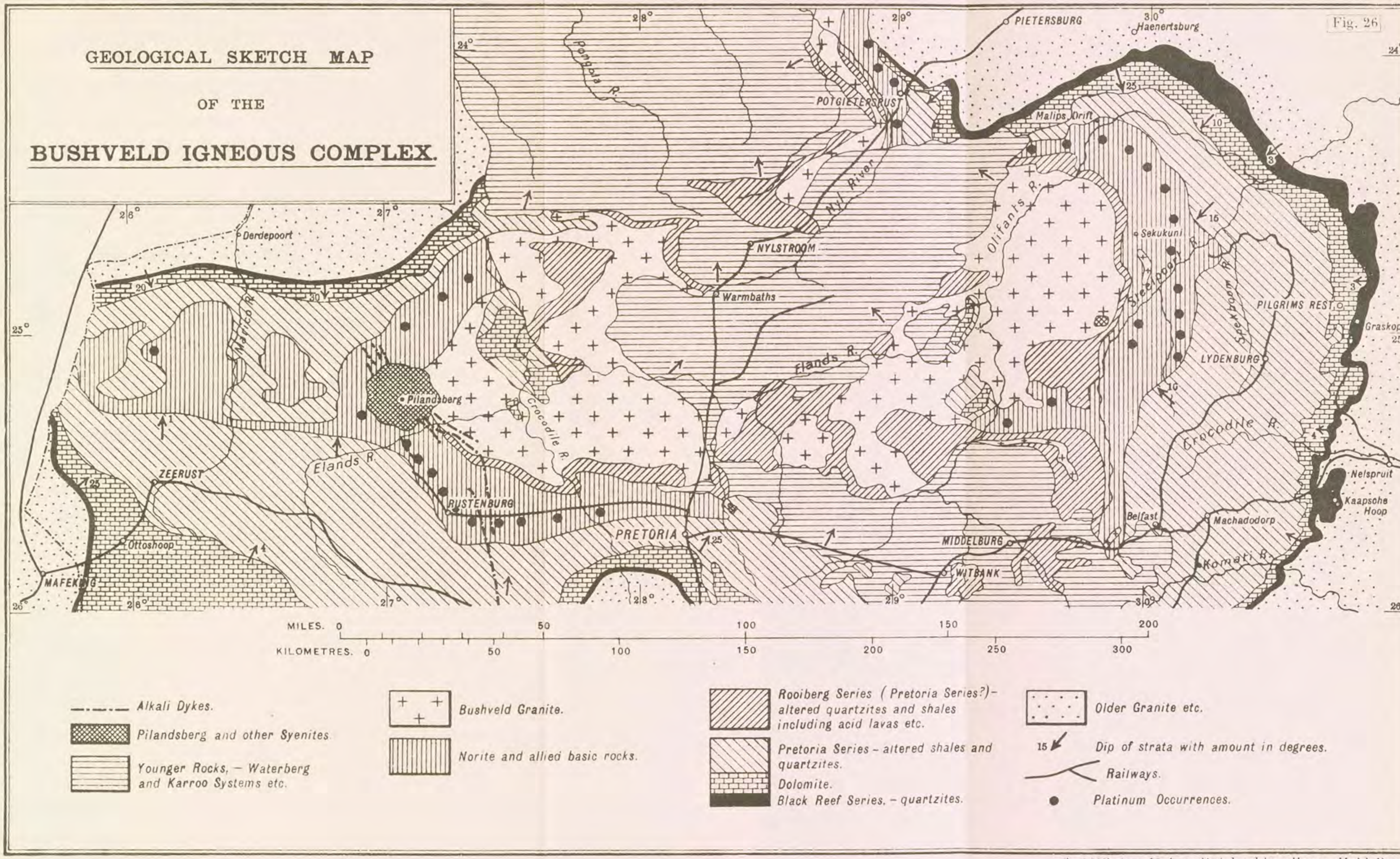


Fig. 26
GEOLOGICAL SKETCH MAP
OF THE
BUSHVELD IGNEOUS COMPLEX.
PIETERSBURG
Haenertsburg
POTGIETERSRUST
Malips Drift
Sekukuni
NYLSTROOM
Warmbaths
PILGRIMS REST
Graskop
LYDENBURG
Derdepoort
Pilandsberg
ZEERUST
RUSTENBURG
PRETORIA
MIDDELBURG
WITBANK
Belfast
Machadodorp
Nelspruit
Kaapsche Hoop
Ottoshoop
MAFEKING
Nyl River
Olifants R.
Elands R.
Crocodile R.
Marico R.
Komati R.
Steelpoort R.
MILES. 0 50 100 150 200
KILOMETRES. 0 50 100 150 200 250 300
Alkali Dykes.
Pilandsberg and other Syenites.
Younger Rocks, – Waterberg and Karroo Systems etc.
Bushveld Granite.
Norite and allied basic rocks.
Rooiberg Series (Pretoria Series?)- altered quartzites and shales including acid lavas etc.
Pretoria Series - altered shales and quartzites.
Dolomite.
Black Reef Series. - quartzites.
Older Granite etc.
Dip of strata with amount in degrees.
Railways.
Platinum Occurrences.

Carl Winters Universitätsbuchhandlung in Heidelberg.

HANDBUCH DER REGIONALEN GEOLOGIE

herausgegeben von

Prof. Dr. **G. Steinmann** (Bonn) und Prof. Dr. **O. Wilckens** (Bonn).

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15. **Antarktis** von Dr. *O. Nordenskjöld* †, Professor an der Universität Göteborg. M. 2.—. (Band VIII, 6.)
16. **Balkanhalbinsel: A. Die Küstenländer Österreich-Ungarns** von Dr. *R. Schubert* † (Wien). M. 3,—. (Band V, 1. a.)

(Fortsetzung umseitig.)