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REPORT ON A STUDY TOUR OF SOUTHERN AFRICA

by

H.G. Roberts

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CONTENTS

FIGURES

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SUMMARY

This record embodies some observations on the Precambrian geology of southern Africa and on mining activity in South Africa, Rhodesia and Zambia.

An attempt is made to summarize current knowledge of the gross aspects of the southern African Precambrian stratigraphic column and attention is drawn to certain similarities between the southern African and Australian columns.

The importance of the mining industry in the economies of South Africa, Rhodesia and Zambia is commented upon and brief descriptions are given of the various mining fields visited during the tour.

INTRODUCTION

The author visited southern Africa between the 7th August and the 6th September 1965. The purpose of the visit was to gain first hand knowledge of the Precambrian rocks of the southern part of the African continent; to study the ore deposits associated with them and to examine the techniques used in mineral exploration and development. About six weeks were spent in the Republic of South Africa, one week in Rhodesia and one week in Zambia.

The aim of this report is to give a brief account of the Precambrian rocks of the southern part of Africa and to draw comparisons between them and their Australian counterparts; to comment on the economic significance of the Precambrian rocks, and to give brief accounts of the major mining centres visited during the tour.

PRECAMBRIAN GEOLOGY

Exposures of Precambrian rocks occupy about one-third of the land area of South Africa; they occur in a broad zone stretching across the northern part of the country and extending southwards along the coastal regions to near Cape Town in the west and to beyond Durban in the east (Fig. 1). Large parts of South-West Africa, Rhodesia and Zambia are also occupied by Precambrian rocks.

Stratigraphic Nomenclature: Discussion of the geology of southern Africa is complicated by the indiscriminate use in the literature of local time-rock terms and by the unsystematic nomenclature applied to rock units. Attempts to rectify this state of affairs are being made, notably by geologists at the University of Cape Town who favour the adoption of a code akin to the Australian code of stratigraphic nomenclature and by the Geological Survey of South Africa (Verwoerd, in press) who favour rationalizing, rather than radically changing, the existing nomenclature. In Zambia progress has already been made in that a distinction is now drawn between lithostratigraphic and chronostratigraphic units (Reeve, 1963).

Precambrian Subdivisions: In general the Precambrian sedimentary rocks have been divided on the basis of unconformities, into a number of Systems, in much the same way as the Australian succession has been divided into Groups. The terms 'Series' and 'Stage' are, in practice applied in more or less the same way as the terms 'Formation' and 'Member' are applied in Australia.

The terms Archaeozoic and Proterozoic are used sparingly in the South African literature; they are generally treated as being of Era rank. The terms Archaean and Algonkian, though used in the same way as the terms Archaeozoic and Proterozoic, are regarded as being of Period rank.

For the most part the Precambrian rocks of southern Africa can readily be fitted into the subdivisions recently proposed for the Precambrian time-scale in Australia. The profound structural unconformity between the Archaean and Proterozoic in Australia is equally evident in southern Africa. The Lower Proterozoic is well represented in southern Africa but no deposits of enequivocable Carpentarian age are known. The Adelaidean is well represented in South-West Africa and Zambia.

For ease of comparison the southern African Precambrian rocks are described under the current Australian scheme of Precambrian nomenclature.

ARCHAEAN

Rocks established as being older than 2500 million years occupy a large tract of country extending from Zambia through Rhodesia and into the Eastern Transvaal, Swaziland and Natal. Correlations between Archaean rocks in the various areas are drawn on Table 2.

In Zambia the rocks are known as the 'Basement Complex' and consist of gneiss, schist, and migmatite with lenticular bodies of crystalline limestone and amphibolite (Reeve, 1963).

In Rhodesia the 'Basement Complex' has been divided into three Systems separated by periods of granite intrusion - the Sebakwian, Bulawayan and Shamvaian.

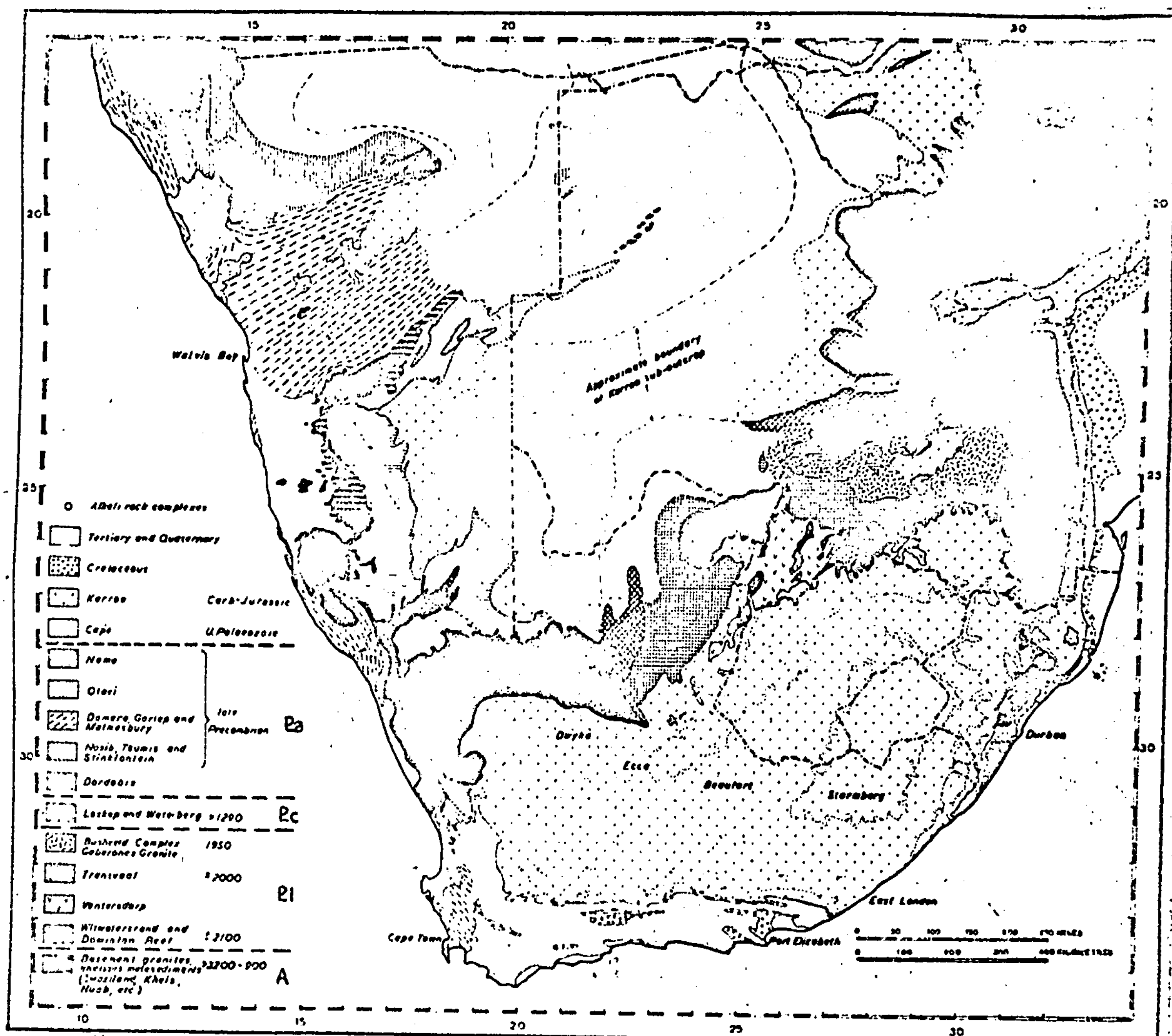


Figure 1 : Geological sketch map of southern part of Africa. A = Archaen, B1 = 'Lower Proterozoic', Bc = Carpentarian, Ba = Adelaidean. (By courtesy of Geology Department, University of Cape Town).

The Sebakwian System contains what are thought to be the oldest rocks in Rhodesia; rock types represented include fine-grained siliceous granulites, mica schists, pelitic schists, hornblende-, actinolite- and talc-schists and serpentinites. Granitization is widespread.

The Bulawayan System is mainly of volcanic origin and comprises great thicknesses of epidiorites and greenstones derived from the metamorphism of basic lavas. Banded ironstone, crystalline limestone, quartzite, schist and phyllite are interbedded with the volcanic rocks. The sequence is intruded by granites. Much of the gold mineralization in Rhodesia is associated with these granites. Apart from the epigenetic deposits there are deposits of syngenetic iron ore (associated with some manganese) in the Bulawayan System.

The Shamvaian System consists chiefly of metamorphosed arkose, greywacke and conglomerate with banded ironstone, phyllite and slate interbeds. They form the country rock at the Shamva gold mine and of a few other small auriferous deposits, but otherwise are not economically significant.

The Swaziland System crops out in Swaziland and in the adjoining parts of the Transvaal. It consists of a great thickness of tightly folded lavas overlain by pelitic rocks and banded ironstones; the Bomvu Ridge iron deposits are part of the Swaziland System.

Rocks of the Swaziland System are unconformably overlain by the Moodies System which consists of a basal conglomerate and a thick succession of quartzitic strata.

Both the Swaziland and Moodies Systems are intruded by granites (e.g. Nelspruit Granite) and basic and ultrabasic rocks (Jamestown Igneous Complex). The Jamestown Igneous Complex has been dated at about 2900 million years and dates on the granites range between 2500 m.y. and 3200 m.y..

In the southern part of South-West Africa further exposures of rocks of probable Archaean age - the Kheis System - occur. The Kheis System is intensely deformed and metamorphosed but in the Richtersveld district it has been divided by De Villiers and Sohnge (1959) into three series as shown below:

Wilgenhoutdrift Series - mafic and felsic lavas (? feet)
Kaaien Series - schist and quartzite (? 20,000 feet)
Marydale Series - mafic and felsic lavas (? 20,000 feet)

The Kheis System is intruded by granites (e.g. the Namaqualand Grey Gneiss) which yield radiometric ages of between 900 and 1090 million years (Nicolaysen, 1962), but Martin (1965, p. 55) argues that the age of deposition of the Kheis System is probably greater than 2600 m.y.

The ages of the Abbabis System and Marienhof Formation of central South-West Africa and the Epupa and Huab Formations of northern South-West Africa are similarly in doubt. The rocks have been intruded by granites with ages of about 1730 million years, and if the Kheis and Abbabis Systems are synchronous as has been suggested by many authors then both would be older than 1730 million years, and using Martin's arguements,possibly Archaean.

'LOWER PROTEROZOIC'

In South Africa the Archaean rocks are overlain with major unconformity by a thick, predominantly shallow-water sequence which was deposited between 2500 and 1950 million years ago and thus may be equivalent at least in part to the Mount Bruce Supergroup of Western Australia. The sequence has been divided on the basis of structurally mild unconformities into four Systems. A summary of the stratigraphy of the sequence is given in Table 1 and a generalized stratigraphic column is shown diagrammatically in Figure 2 where it is compared with the Western Australian sequence.

The Dominion Reef and Witwatersrand Systems appear to have been deposited over a much more restricted area than the younger Ventersdorp and Transvaal Systems. The Witwatersrand System is by far the most important economically as it contains most of the gold deposits of South Africa. Iron ore is being mined from the Transvaal System at Thabazimbi, and the extensive crocidolite deposits of the northern Cape Province are also in the Transvaal System.

The Dominion Reef System rests unconformably on granites which yield radiometric ages of between 2500 and 3200 million years; in the Pilbara region of Western Australia granites forming the 'basement' to the Mount Bruce Supergroup yield ages of from 2300 to 3000 million years (Leggo, Compston and Trendall, 1965). The South African succession is intruded by the Buchveld Complex which has given a radiometric age of 1950 million years and the Mount Bruce Supergroup is intruded by a granite which has given an age of 1720 million years (Leggo et al, 1965). A tuffaceous siltstone from high in the Supergroup has yielded an indicated maximum age of 1850 million years but this value is, in the words of Leggo et al, op. cit.) "subject to uncertainty"; acid volcanics high in the Hamersley Group give a more reliable age of 2100 million years.

Thus the time limits within which the two successions were deposited are wide and there is no clear evidence to show that the successions are necessarily contemporaneous, even in part. However lithogenetically similar sequences (e.g. the Carpentarian strata of northern Australia) have been shown to have accumulated very slowly in comparison to the other lithogenetic associations, and it may be surmised that the South African 'Lower Proterozoic' column is likely to contain actual representatives of a substantial part of the 2500-1950 m.y. time interval. The more complete the South African sequence is, the more likely it is to contain actual time-representatives of the Australian record.

In some respects the gross lithological features of the two successions are strikingly similar (Fig. 2). It is perhaps more than coincidence that the Ventersdorp System (14000 feet of andesite with minor arkose, limestone and chert) and the Fortescue Group (22000 feet of basalt with minor quartzite, arkose, chert and dolomite) are overlain by sequences with many lithological and superpositional similarities. Of particular interest is the occurrence of banded iron ores, crocidolite, stromatolite-bearing dolomite and basalt in broadly similar "stratigraphic" positions.

Only further age determinations will show if the Mount Bruce Supergroup was in fact deposited contemporaneously with the Ventersdorp and Transvaal Systems, but there is no doubt that the sequences were deposited in basins with extraordinarily similar tectonic histories and environments of sedimentation.

Stromatolites are abundant in the Transvaal System (Dolomite Series) and although a few occurrences have been described by Young (1932, 1934) and Young and Mendelssohn (1948) no thorough study of them has been made. Winter (1963) has recently described stromatolites from bore-cores of the Ventersdorp System. Although most authors reject the notion that stromatolites can be of use in a time-stratigraphic sense, Russian workers, notably Vologdin (1962) have shown that quite different assemblages characterize particular intervals of the Precambrian time-scale, and this gives hope that detailed studies of the

TABLE 1: Summary of the stratigraphy of the 'Lower Proterozoic' succession of the Transvaal, South Africa. Thicknesses are shown in feet.

SYSTEM	SERIES	STAGE		
		Magaliesburg (9500)	Quartzite	1000
			Shale (and dolerite	8500
			Quartzite	250
		Daaspoort (3900')	Shale	600
	Pretoria (14000-24000)		Ongeluk lava	2000
			Shale	1000
			Quartzite	200
TRANSVAAL (30,000)		Timeball Hill (1400)	Shale	250
			Quartzite	250
			Shale, conglomerate	700
	Dolomite (120-7000)		Dolomitic limestone, chert, shale, banded ironstone	
	Black Reef (100-2500)		Quartzite, conglomerate	
VENTERSDORP (11000-14000)			Andesite, arkose, limestone, chert	
	Kimberley-Elsburg (6000)			
	Main-Bird (2000)		Quartzite, conglomerate (major gold deposits)	
WITWATERSRAND (25,000)	Jeppestown 2500			
	Government Reef 7500		Alternating shale and quartzite	
	Hospital Hill (6000)			
DOMINION REEF (2000-3000)			Basic and acid lavas	

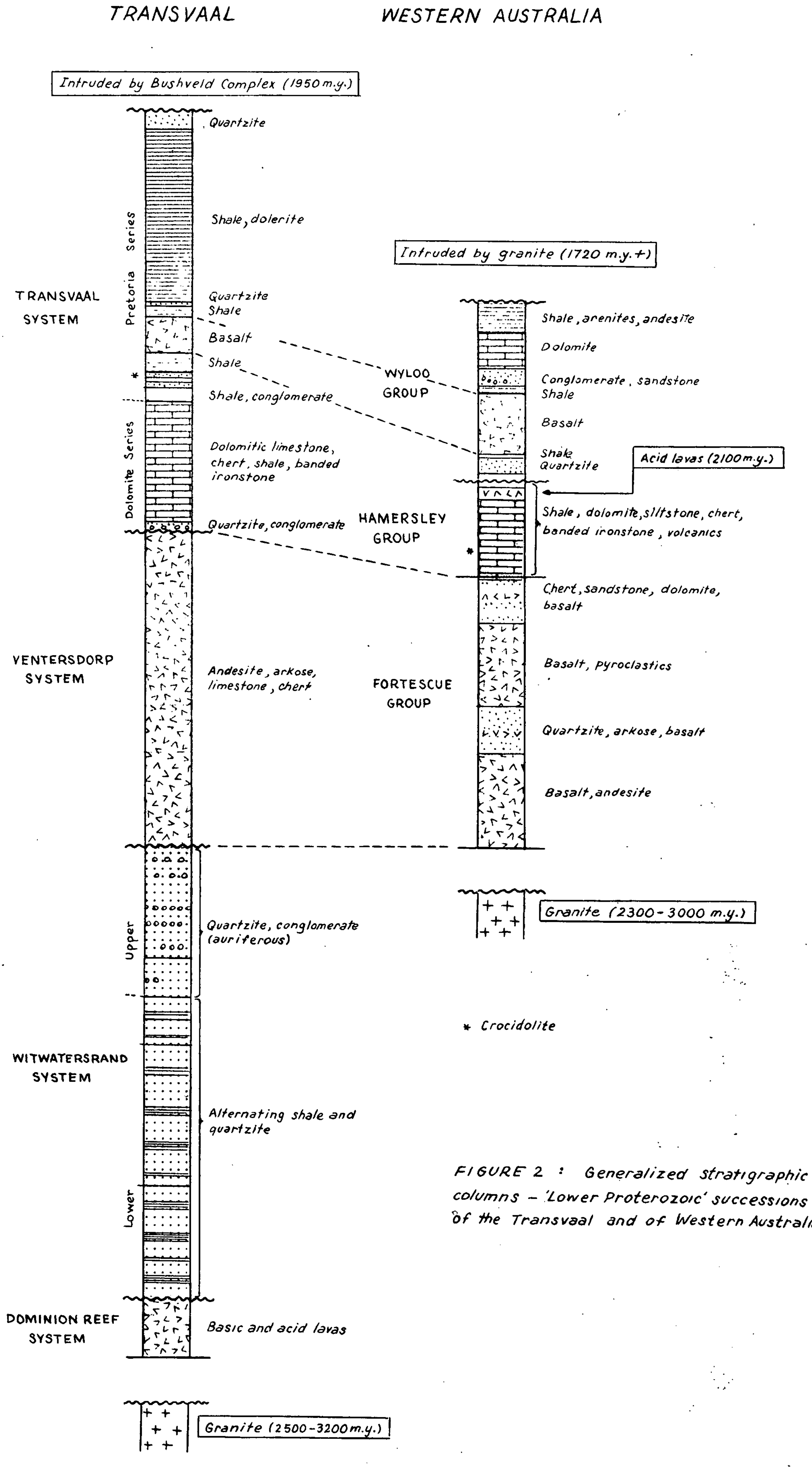


FIGURE 2 : Generalized stratigraphic columns – 'Lower Proterozoic' successions of the Transvaal and of Western Australia

1966/217

TABLE 2 CORRELATION CHART – MAJOR SUBDIVISIONS OF THE ARCHAEAN* AND 'LOWER PROTEROZOIC'* ROCKS OF SOUTHERN AFRICA

<table>
<tr><th></th><th>ZAMBIA</th><th>RHODESIA</th><th>NATAL-SWAZILAND</th><th>TRANSVAAL</th><th>BECHUANALAND</th><th>GRIQUALAND WEST</th><th>SOUTH-WEST AFRICA</th></tr>
<tr><td rowspan="7">LOWER PROTEROZOIC</td><td rowspan="7">MUVA GROUP</td><td>GREAT DYKE</td><td rowspan="7"></td><td colspan="2">BUSHVELD COMPLEX (1950 m.y.)</td><td></td><td rowspan="7"></td></tr>
<tr><td>LOMAGUNDI AND UMKONDO SYSTEMS</td><td colspan="3">TRANSVAAL SYSTEM</td></tr>
<tr><td>Granite intrusion</td><td colspan="3" rowspan="2">VENTERSDORP SYSTEM</td></tr>
<tr><td>DEWERAS SYSTEM</td></tr>
<tr><td>FRONTIER SYSTEM</td><td>WITWATERSRAND SYSTEM</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Tonalitic granites</td><td>Palala Granite</td><td>Gaberones Granite</td><td rowspan="2">Koras and Zoetlief</td></tr>
<tr><td colspan="2">DOMINION REEF SYSTEM</td></tr>
<tr><td rowspan="4">ARCHAEAN</td><td colspan="6">Widespread granitization, granite intrusion and mineralization (2500–3200 m.y.)
Jamestown and Rooiwater Igneous Complexes (2900 m.y.)</td><td></td></tr>
<tr><td rowspan="3">BASEMENT COMPLEX</td><td>SHAMVAIAN SYSTEM</td><td>Nkandhila
MOODIES SYSTEM</td><td rowspan="3">Messina</td><td rowspan="3">BASEMENT COMPLEX</td><td rowspan="3">Kraaipan</td><td rowspan="3">KHEIS and ABBABIS SYSTEMS Epupa, Huab and Marienhof Formations</td></tr>
<tr><td>BULAWAYAN SYSTEM</td><td rowspan="2">Nondweni
Mfongosi
SWAZILAND SYSTEM</td></tr>
<tr><td>SEBAKWIAN SYSTEM</td></tr>
</table>

* Used in the Australian sense.

stromatolite assemblages of the South African and Australian 'Lower Proterozoic' sequences may lead to closer correlation.

CARPENTARIAN

On present evidence southern Africa, in common with southern Australia, appears to be devoid of sedimentary rocks of Carpentarian age (that is between 1800 and 1400 million years old). However the Waterburg and Loskop Systems which unconformably overlie the Transvaal System and the Bushveld Complex (1950 m.y.) in the central Transvaal are post-dated by igneous rocks dated as 1290 million years old and could possibly have been deposited during the Carpentarian. The sequence consists of purple arenites and rudites and attains a thickness of several thousand feet.

The Sijarra Series of Rhodesia is of similar lithology and may be equivalent to the Waterburg and Loskop Systems although Nicolaysen (1962) suggests that the Series could be as young as Palaeozoic.

ADELAIDEAN

In southern Africa the Adelaidean Period was marked by the development of a great geosynclinal zone (the Damara Geosyncline, see figure 3) extending from southern South-West Africa to the north-east, probably as far as the Congo (Martin, 1965). The geosyncline may have extended south through the Richtersveld district to the Cape Town area. It was flanked to the south-east by the Kalahari Craton and to the north-west by the Congo Craton (Clifford, 1965).

The sequence in the geosyncline is as yet known only in reconnaissance detail and many important problems of correlation remain unresolved. Their resolution is of particular interest in that the sequence is one of the better records of late Precambrian history. Professor E.S.W. Simpson (pers. comm.) of the University of Cape Town and Martin (1965) have suggested the correlations set out in Table 4.

Sedimentation in the geosyncline appears to have begun about 1000 million years ago and continued, with occassional interruptions to either late in the Precambrian or early in the Palaeozoic, when orogenesis and the emplacement of granites with ages ranging from 520 to 600 million years brought the development of the geosyncline to a close.

Perhaps the oldest sediments of the geosyncline are those of the Gariep System of the Richtersveld. De Villiers & Sohnge (1959) divided the Gariep System into four Series:-

GROOTDERM SERIES (27,000')	schist, greywacke (14,000') schistose andesite (13,000') schist, minor quartzite, greywacke and arkose
HOLGAT SERIES (30,000')	quartzite, schist schist, greywacke, minor conglomerate quartzite and tillite (50-100) schist, minor arkose and greywacke arkose, greywacke
HILDA SERIES (10,000-35,000')	schist, grit, arkose, dark limestone, conglomerate
BLACK HILLS SERIES (3,000')	limestone, phyllite, schist 400' tillite and schist 800' limestone, quartzite, schist 300' tillite, schist, quartzite 1500'

They recognized three tillitic zones in the sequence; the older two probably jointly represent a single major glacial episode. The uppermost tillite is from 50 to 100 feet thick and is, perhaps, of less correlative significance than the older tillitic suite.

In central South-West Africa the Abbabis System (possibly Archaean) is unconformably overlain by the recently recognized Dordabis System which consists of basic to acid lavas and quartzitic sediments and is up to 22,000 feet thick. The System is thought to be younger than the Gariep System and is correlated with the Khoabendus Formation of northern South-West Africa and the Sinclair, Kapok and Auborus Formations in the south (E.S.W. Simpson, pers. comm.).

In northern and central South-West Africa the Dordabis System is unconformably overlain by the Nosib Formation which consists of conglomerate and quartzite and is up to 16,000 feet thick. It extends onto the northern platform area of the Damara Geosyncline in northern South West Africa and Angola. It may be a stratigraphic equivalent of the Tsumis Formation of central South West Africa and the Stinkfontein Formation of the Richtersveld which both flank the south-eastern parts of the Geosyncline. The Stinkfontein Formation consists mainly of quartzite and conglomerate with interbeds of trachyte and andesite and is up to 30,000 feet thick; it rests unconformably on the Kheis System and on the 'Grey Gneiss'. Its relationship to the Gariep System is not clear but it is thought to be younger. Two main conglomeratic zones are recognized but they do not persist throughout the lateral extent of the Formation. The unit is known to be younger than 900 m.y..

The Stinkfontein Formation is unconformably overlain by the Kaigas Formation which consists of up to 1500 feet of tillite with quartzite interbeds; the unit is believed by Martin (1965, p. 99) to be equivalent in part to the Numees Formation which is made up of (from top to bottom):-

Tillite and dolomite	2000'
Dolomite	100'
Arkose and grit	400'
Dolomite	100'

In the main geosynclinal belt the Nosib Formation is unconformably overlain by rocks of the Damara System - the sequence is generally about 25,000 feet thick and has been divided into two series - the lower 'Hakos Series' which consists of crystalline limestone and dolomite (and includes the Chuos Tillite), and the upper Khomas Series which consists of crystalline schist with subordinate quartzite and marble.

To the north the Hakos and Khomas Series are thought to grade laterally into a relatively unmetamorphosed and little-folded miogeosynclinal platform facies - the Otavi Series at the base, overlain by the Mulden Series. These rocks have been placed in the Otavi System by du Toit (1954) and other authors but are now regarded as part of the Damara System. The platform rocks are known as the Outjo Facies and the geosynclinal deposits are known as the Swakop Facies. The Tsumeb lead-zinc and copper deposits occur in the Otavi Series. The Series is generally about 10,000 feet thick and consists mainly of dolomite. The dolomite is mostly light grey but near the top it becomes black and fetid and contains black chert and oolitic limestone beds. A tillite has been reported from the middle part of the Series (Le Roux, 1941).

The Nama System which is exposed extensively in the southern part of South West Africa is regarded by some authors as being a stratigraphic equivalent of the Damara System. In the north it rests conformably on the Tsumis Formation but in the south it rests with possible unconformity on the Numees Formation. The System is divided into four series:-

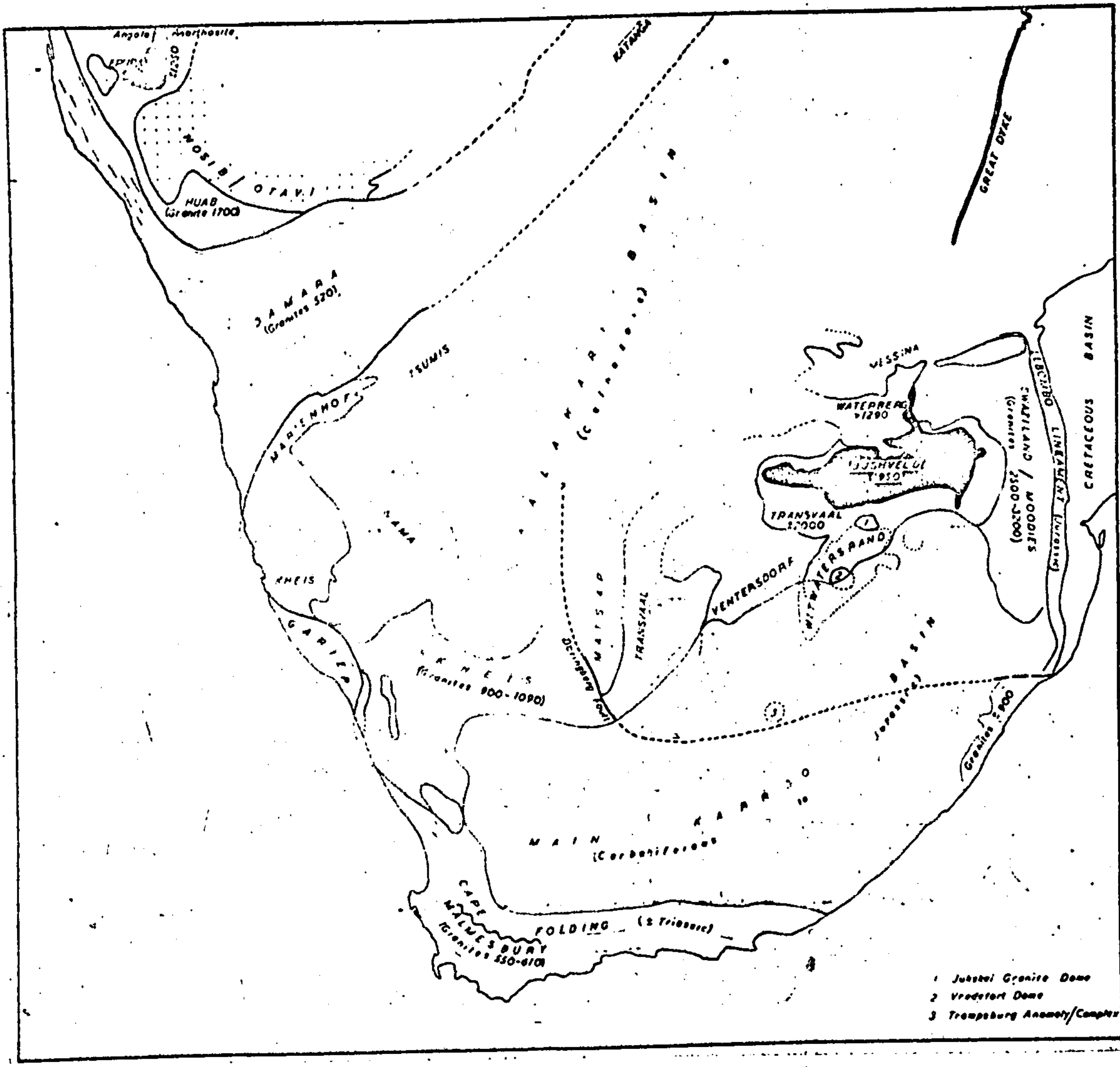


Figure 3 : Major structural elements - southern Africa (by courtesy of Geology Department, University of Cape Town).

TABLE 4 : CORRELATION OF PRE-CAMBRIAN FORMATIONS IN THE WESTERN CAPE AND SOUTH WEST AFRICA

SYSTEM	NORTHERN S.W.A.	CENTRAL S.W.A.	SOUTHERN S.W.A.	NAMAQUALAND (S. of Luderitz-Arcab) and Upington district.	SOUTH & SOUTH-WEST CAPE
	Post-Damara granites (520 m.y.)		Tiras granite ?	Kuboos granite ?	Cape granite (560 m.y.)
DAMARA/NAMA	DAMARA: Outjo Facies Mulden Series Upper Otavi Otavi Tillite ● Lower Otavi	DAMARA: Swakop Facies Khomas Series Upper Hakos Chuos Tillite ● Lower Hakos	(Buschmannsklippe Formation) ●	NAMA: Fish River Series Schwarzrand Series ● Schwarzkalk Series Kuibis Series Numees Formation ● Kaigas Substage	Malmesbury and Cango Formations
	Nosib Form. (ex Hundskopf)	Nosib Form. (ex Quartzite & Duruchaus Ss.)	Tsumis Formation	Stinkfontein Formation	(Klipheuvel, Fransch Hoek ?)
DORDABIS	Khoabendus Formation	DORDABIS: Doornpoort Series Skumok Series Opdam Series	AUBORUS FORMATION Sinclair & Kapok Forms.		
GARIEP	MAJOR UNCONFORMITY			GARIEP: ** Grootderm Series Holgat Series ● Hilda Series ● Black Hills Series ●	
	Ang. Anorth. (1260 m.y.)		Widespread granites (± 1000 m.y.)		

** Martin (1962, p. 83) suggests that the Gariep System may be younger than the Kapok Formation.
● Denotes tillite present in sequence.

Fish River Series	2300'	Red and purple sandstone, shale and siltstone
Schwarzrand Series	1150'	Grey-green to bluish grey shale. Limestone. Tillite lense near top.
Schwartzkalk Series	1000'	Fetid dark grey to blue-black limestone.
Kuibis Series	660'	Feldspathic quartzite, red shale.

The Adelaidean rocks of South-West Africa are separated, in outcrop, from those in Zambia by a cover of rocks of the Karoo System and by the sands of the Khalahari Desert. In Zambia the Adelaidean sequence is known as the Katanga Supergroup (Reeve, 1963); the sequence has been studied in most detail in the Copper belt, but because of the generally poor outcrop much of the stratigraphic column is poorly known. The sequence is thought to underlie much of the area of Zambia.

The Supergroup rests unconformably and the quartzites and schists of the Muva Group and on granites. It is divided by Reeve (op. cit) into three Groups (Table 3).

TABLE 3 : Subdivisions of Katanga Supergroup and their thicknesses and lithologies.

Subdivisions of Katanga Supergroup (after Reeve, 1963; Mendelsohn, 1961)			Lithology & Thickness (after Mendelsohn, 1961)	
KUNDELUNGU GROUP	UPPER		Shale, quartzite	
	MIDDLE		Shale	
			Tillite	
			Shale	
	LOWER	KAKONTWE LS	Dolomite, shale	1500
			Tillite	100-500
MWASHIA GP			Shale, argillite	500-2000
ROAN GROUP	UPPER		Dolomite, argillite	1200-2200
			Argillite, quartzite	
	LOWER 0-3000'	HANGINGWALL	Quartzite Argillite & feld. qtzite	200-800
		ORE	Argillite, dolomite, micaceous quartzite	200
		FOOTWALL	(Footwall Conglomerate)	1000
			Argillaceous quartzite	
			Feldspathic quartzite	
			Aeolian quartzite	
			Conglomerate	

The Supergroup extends into the Congo and although a different nomenclature is applied, the subdivisions are essentially the same. Furon (1963, p. 281) gives details of the succession in the Congo where the Mwashia Group is regarded as being partly of glacial origin.

The copper deposits of Zambia occur in the lower part of the Roan Group and the Congo deposits in the upper.

Comparison of African and Australian Adelaidean Sequences:

The widespread distribution of tillites in late Precambrian sequences in Africa, Australia and on other continents affords, if it is assumed that the tillites are reflections of global climatic changes, a means of chronologically relating the various sequences. Figure 4 is an attempt to correlate the late Precambrian sequences of southern Africa and Australia - radiometric age determinations provide evidence of the broad contemporaniety of the various successions, and the tillites have been used to suggest closer correlations.

A feature of special interest is that the older of the two major glaciations appears to have had two optima - in most places normal clastic sediments occur in the middle of the tillitic sequence. The younger glaciation may possibly have been of shorter duration than the older because in every succession the younger tillite is thinner than the older.

A surprising aspect of the tillites is their almost ubiquitous stratigraphic association with carbonate rocks. Two particular rock types, both otherwise rare in the geological record, are exceptionally common within a few hundred feet stratigraphically above and below many of the tillites. One type, a pink, regularly laminated dolomite occurs immediately on top of many of the younger tillites. In places similar beds directly underlie the tillites. The second type, a massive, black, fetid, carbonaceous limestone is commonly present a few hundred feet above and less commonly, below the tillites. It is possible that both types may be indicative of specific epi-glacial environmental regimes. Detailed studies of the carbonates, particularly of their chemical composition could possibly yield information on the composition of the late Precambrian seas and atmosphere.

THE MINING INDUSTRY

Early History

A surprising feature of the mining industry in southern Africa is its antiquity. When Europeans first arrived they found that iron, copper, tin and gold had already been mined, in places on a substantial scale. Some of the workings may be as much as 1500 years old. The following outline is taken largely from Pelletier (1964).

The smelting of iron was prevalent in southern Africa before AD 1500. Hematite was the main ore used - it was packed in small clay furnaces in alternating layers with charcoal and green twigs, and subjected to a forced draught from bellows made of hides.

Ancient copper workings are widespread in southern Africa and some attain large dimensions. The main workings were in the Katanga copperbelt where the richest outcrops of copper ore were to be found. Most of the modern copper mines in the Congo are situated near ancient workings. At the 'Star of the Congo' mine the old workings were three-quarters of a mile long and from 600 to 1000 feet wide. Other important workings were at Messina and Palabora and Tsumeb, three modern mining centres. Malachite appears to have been virtually the only ore used and it was smelted in the same way as hematite.

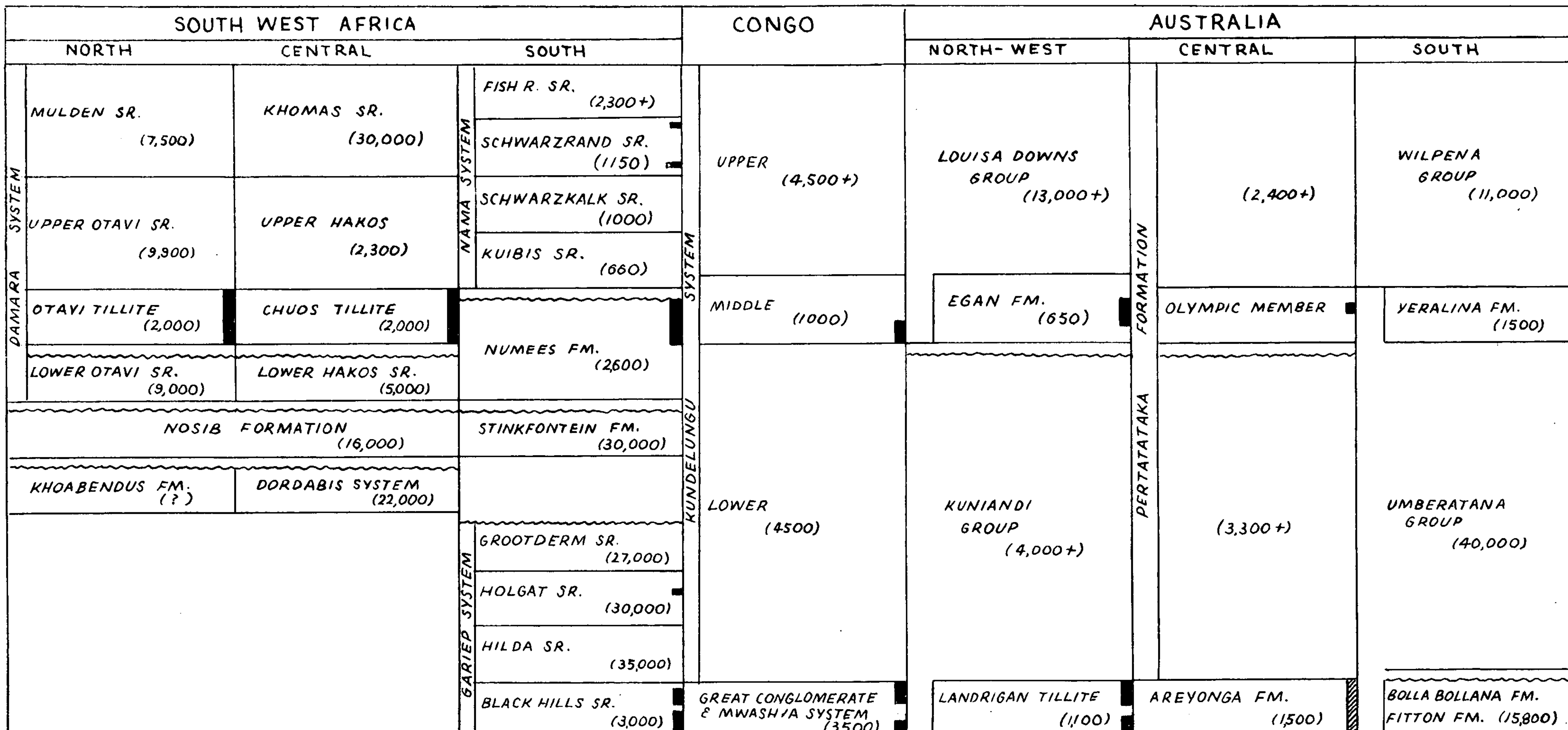


FIGURE 4 : Correlation of late Precambrian sequences of southern Africa and Australia assuming equivalence of tillites. Tillites shown by dark rectangles. Wavy line denotes unconformity; figures in brackets denote thickness in feet.

1966/217 HGR

Extensive pre-European tin workings are found at Rooiberg and Leeuwpoort north of Pretoria. About 40 acres were closely pitted over a length of two-thirds of a mile and a width of about 600 feet. Evidence of ancient smelting works is still preserved at Smelters Kop about a mile and a half from the Rooiberg workings. It has been estimated that 18,000 tons of ore were mined at Rooiberg and a similar amount at Leeuwpoort for the production of 2000 tons of metal alloy. (The ore contains copper as well as tin).

Ancient gold workings are confined mostly to Rhodesia, but here exploration was particularly intensive - every gold-bearing outcrop known in Rhodesia has signs of having been worked by pre-Europeans.

The ore was mined in open trenches and in small shafts or pits; no workings were carried out below the water-table and very few below 40 or 50 feet. Several million ounces of gold are thought to have been won.

The Modern Industry

The mining industry plays a particularly important part in the economics of southern African countries.

The value of mineral production in South Africa in 1963 (Department of Mines, 1965) was £A632 million compared with £A207 million for Australia in the same year (Table 5). Production has increased sharply in the past few years and in 1964-65 no less than 52% or about £A600 million of the country's export income was derived from mineral commodities. This compares with 7% for Australia.

Table 5: Total value of mineral production, percentage of export income derived from mineral commodities and number employed in the mining industries of South Africa, Rhodesia, Zambia and Australia. Figures are approximate.

	SOUTH AFRICA (1963)	RHODESIA (1964)	ZAMBIA (1964)	AUSTRALIA (1963)
Total Value of Minerals	£632 m.	£33 m.	£230 m.	£207 m.
% of Exports	52%	20%	90%	7%
Number Employed	667,000	40,000	50,000	130,000

Gold is by far the most important of the minerals produced in South Africa as it accounts for about 70% of the total value of production; uranium and coal each account for about 7% of the total value; diamonds, asbestos, copper and manganese are other significant contributors (Table 6). Petroleum and bauxite are the main mineral deficiencies.

The industry employs 667,000 people, some 90,000 of whom are Europeans; 444,000 are engaged in the gold mining industry. About 60% of the Bantu work force come from countries outside the Republic.

The economics of the gold mining industry in South Africa has recently been discussed by Cross, (1965). Between 1955 and 1965 the average cash earnings of white employees has risen from R 1943 (£1215) per annum to R 2861 (£1790) - an increase of 47%, and the average cash earnings of non-white employees has risen from R 132 (£82) per annum to R 165 (£103) - an increase of 25%.

In the same period the working costs per ton of ore milled have risen from R 4.04 (£2.10.-) R 5.49 (£3.8.9), an increase of 36%.

The steady increase in working costs has lead to an increase in the grade of ore milled and a consequent reduction (in some cases irrecoverable) in the life of the mines. The current average working profit per ton of ore milled is about £2.6.-.

It is unlikely that it will be possible to peg wages and the industry must look to increased productivity to offset rising costs. However during the last 10 years the Europeans have received a 47% increase in wages while their productivity has gone up by only 30%. In the case of the Bantu labourers an overall wage increase of 25% has resulted in virtually no increase in productivity at all.

Of the approximately R 1000 million revenue from gold production in 1964 the following amounts are disbursed to the Government, Shareholders and Employees:-

Government:		
From Government ownership	R 30 m	
From Taxes	R 87 m	R 117 m
Shareholders (Dividends)		R 125 m
Employees		
Whites	R 130	
Non-Whites	R 62 m	R 192 m

It would seem that should costs continue to rise the Government will eventually be forced to forego its tax revenue.

As profitability of the mines decreases (as is inevitable in the next few years because of depletion of the higher grade ore reserves), new capital investment becomes less likely, but production from existing mines appears likely to continue for many years. Gold production is currently running at about 30 million ounces per annum; the industry predicts that, short of a rise in the price of gold, production will begin to fall in 1966 and that within 10 years it will have fallen to 20 million ounces.

Zambia's annual mineral production is valued at about £A 230 million; copper accounts for some £A 225 million of this amount (at producers price of £188 sterling per ton) and zinc, lead, cobalt and silver make up most of the balance. About 90% of the country's export income is derived from the mining industry. The industry is responsible for nearly 40% of Zambia's wage bill and 56% of the Government's revenue.

In 1964 Rhodesia produced about £A 33 million worth of minerals. Gold (27% of total value), asbestos (25%), copper (16%), coal (13%) and chrome ore (8%) made up 90% of the production. The production of iron ore rose to almost 1 million tons in 1964 in response to Japanese orders but the capacity of the railways to handle the ore has, for the time being, reached its limit.

Apart from tobacco, minerals are Rhodesia's main export and in normal times provide about 20% of the country's export income.

NOTES ON MINING FIELDS

During the tour an effort was made to visit as many of the major mining centres as possible. Visits were made to diamond mines near Kimberley and Pretoria; gold mines on the Witwatersrand and in the Orange Free State; manganese and asbestos mines near Postmasburg; phosphate and copper workings at Palabora; ironstone workings at Bomvu Ridge (Swaziland); chromite mines at Selukwe in Rhodesia and the Broken Hill lead-zinc mine and the Copperbelt in Zambia.

Table 6 : Production and value of various minerals mined in South Africa and Australia in 1963. (Source - Government Publications).

Product	Production (tons)		VALUE £Am.	
	SOUTH AFRICA	AUSTRALIA	SOUTH AFRICA SALES 1963	AUSTRALIA EX-MINE
Gold	27.4 m.02	1.0 m.02	448.0	14.7
Silver	2.7 m.02	19.5 m.02	1.6	8.8
Uranium Oxide	4,537	1,084	42.0	10.0 ?
Chrome ore & canc	873,212	160	3.0	-
Copper	60,085	112,746	13.4	25.2
Iron Ore	4,916,048	5,514,562	7.5	6.1
Lead	-	610,357	-	27.9
Manganese	1,496,790	36,204	8.4	-2
Tin	?	2,852	1.7	3.1
Zinc	-	351,428	-	8.1
Ilmenite	31,039	203,423	.2	.7
Rutile	1,385	183,683	.1	5.8
Zircon	2,648	183,903	.1	1.8
Asbestos	205,743	13,374	13.8	1.2
Coal-black	46,797,958	24,857,461	42.0	59.1
brown	-	18,456,642	-	8.6
Iron pyrites	461,376	194,044	1.7	1.4
Limestone & Dolomite	8,216,151	6,761,440	5.7	4.3
Phosphates	501,456	4,925	2.5	-
Salt	218,015	582,787	1.2	1.2
Vermiculite	98,758	-	.8	-
Diamonds	4,274,676	-	22.8	

Total ex-mine value of minerals produced in 1963 -:

South Africa £632 m.
Australia £207 m.

Kimberley Diamond Mines: The first diamonds discovered in South Africa were found along the Orange River in 1866 and by 1870 three intrusive diamond-bearing pipes had been discovered near Kimberley; the famous De Beers and Kimberley pipes were discovered in the following year.

A group of small, but rich, fissure deposits to the north-east of Kimberley were found between 1906 and 1912. Further discoveries culminated in the recognition of alluvial diamonds near the mouth of the Orange River. Recent discoveries include a pipe near Kimberley which is of even greater size than the Premier pipe (near Pretoria).

Five pipes occur in the immediate vicinity of the city of Kimberley. They vary in size from 10 to 32 acres at the surface and tend to decrease in diameter with depth.

Initially the pipes were worked from the surface from claims measuring 31 feet x 31 feet, distributed among a large number of claim holders. As mining proceeded operations became increasingly difficult due to rock falls and a series of mergers took place, eventually leading to the formation of the De Beers Consolidated Mines in 1888 - Cecil Rhodes was involved in the formation of the Company. Three of the pipes are still being worked.

Kimberlite, the host rock to the diamonds is a porphyritic ultrabasic rock. Olivine, partly or wholly altered to serpentine, enstatite and diopside are the most important constituents and ilmenite, phlogopite and garnet are commonly present.

Premier Diamond Mine: The Premier diamond mine is 25 miles east of Pretoria. Diamonds were discovered there in 1902 by Sir Thomas Cullinan, and excavations began in 1903; in 1905 the famous Cullinan Diamond, weighing 3,106 carats, or about 1.37 pounds was discovered in the mine and was bought by the Transvaal Government for £150,000. Paradoxically although the Cullinan Diamond is the largest diamond yet discovered, the Premier mine is the source of the smallest recoverable diamonds and over 80% of the production is of industrial stones. Production in 1963 amounted to 2.1 million carats valued at about £4 million Australian from over 5 million tons of ore.

The diamonds occur in a roughly elliptical Kimberlite pipe about 2,800 feet on the long axis and 1400 feet on the short axis. The pipe is vertical and intrudes a post-Waterburg System syenite (Visser et al., 1961). A large 'raft' of quartzite of the Waterburg System is present in the mine.

The mine was worked by open-cast methods to a depth of 610 feet from 1902 to 1932; it was closed from 1932 to 1945 and since 1945 it has been worked from an externally sited vertical shaft. A trench 45 feet wide and 300 feet in depth is cut along the long axis of the pipe; the walls of the trench are stepped in benches at vertical intervals of 50 feet to form a slope of 65°. Lines of 68 foot square caves are excavated in the bottom of the trench and serve as funnels to convey newly blasted blue-ground to the underground haulage system. The blue-ground passes through grizzlies set to 23", and then is railed to the main shaft where it is reduced to 6 inch size before hoisting.

Witwatersrand Goldfields: Gold was discovered near the present city of Johannesburg in 1886 and since that time almost 1000 million ounces (31,250 short tons) of gold have been won from the surrounding region. About 2500 million short tons of ore have been mined - an average grade of about 8 weights. Current production is about 30 million ounces per annum from about 90 million tons of ore.

The Witwatersrand goldfields include three principal mining districts - the Witwatersrand proper, the Klerksdorp area, the Orange Free State area, and the Kinross area.

The gold occurs in conglomerates of the Witwatersrand System which for the most part lies in a completely enclosed structural ~~basin~~, elliptical in outline, some 180 miles long and 100 miles across. A dome in the centre of the Basin (the Vredefort Dome) modifies the simple synclinal form. Much of the Basin is covered by rocks of the Karroo System.

For the first forty years mining was confined to the northern part of the Witwatersrand Basin, but it had been realized that the existing field occupied only part of a much larger basin of Witwatersrand System sediments. In 1930 the field was extended westwards and in 1933 exploration began in the northern part of the Orange Free State. Five years later drilling gave the first indications that a new field had been discovered in the Free State. This was a notable development because the entire area was covered by Karroo System sediments.

By 1952 the broad outline of the Basin had been delimited and the major economically important areas had been fairly well defined. Since then exploration has been confined mainly to more closely defining the known ore bodies and to searching for further synclines beneath the cover of the younger rocks. One such syncline (of small extent) has recently been discovered to the east of the Witwatersrand Basin.

The gold-bearing conglomerates are confined principally to the upper part of the Witwatersrand System. Only relatively few of the beds are economic but these are remarkably persistent. The conglomerates consist of pebbles of white, colourless, grey or black vein quartz, fine-grained quartzite and grey chert set in a sandy silicified matrix. Grains of chromite, iridosmine, zircon, tourmaline, diamond and uraninite occur in accessory amounts. Pyrite is common and carbon is present locally; the latter is commonly associated with rich pockets of free gold.

Although some authors, notably Davidson (1960) favour a hydrothermal origin for the gold mineralization, there is widespread support for a sedimentary origin. Proponents of the latter admit that most, if not all of the gold has been at one time or another redistributed within individual conglomerate beds but point to the ubiquitous association of the gold with a particular suite of detrital minerals as being clear evidence of a sedimentary origin. One particular gold-bearing conglomerate bed - the "Ventersdorp Contact Reef" - has been shown to have been derived from the erosion of older auriferous conglomerates, and it is evident that gold was present in the Witwatersrand System prior to the extrusion of the lavas which make up the Ventersdorp System. The "Ventersdorp Contact Reef" is lithologically similar to the other auriferous conglomerates and this is further evidence of a sedimentary origin for the gold.

<u>Postmasburg Manganese Field</u>: Manganese ore was discovered near Postmasburg (about 100 miles west of Kimberley) in 1922. Despite the isolation of the region (700 rail miles from the coast) the production of ore has grown rapidly and in 1963 the field produced most of the 1½ million tons of ore won in South Africa.

The Postmasburg district is underlain by thrust-faulted sediments of the Transvaal System. The thrust faulting has led to the development of extensive tectonic breccias which have played an important part in localizing the mineralization. The manganese is believed to have been derived from dolomites of the Dolomite Series by prolonged leaching, and to have been redeposited in the tectonic breccias. The breccias are generally only mineralized where they are in contact with dolomite.

The ore bodies extend only to shallow depths and are mined by open cut methods. De Villiers (1960, p. 101) has estimated the reserves of ore in the Postmasburg area to be about 50 million tons. Extensive deposits of iron ore, developed by similar processes of concentration from banded ironstones, are present in the region.

Cape Province Crocidolite Deposits: In 1963 over 200,000 short tons of asbestos was produced in South Africa. About half was crocidolite, 35% amosite and 15% chrysotile. Most of the crocidolite was mined in the northern part of the Cape Province. Mining of crocidolite in the Cape Province began in 1893.

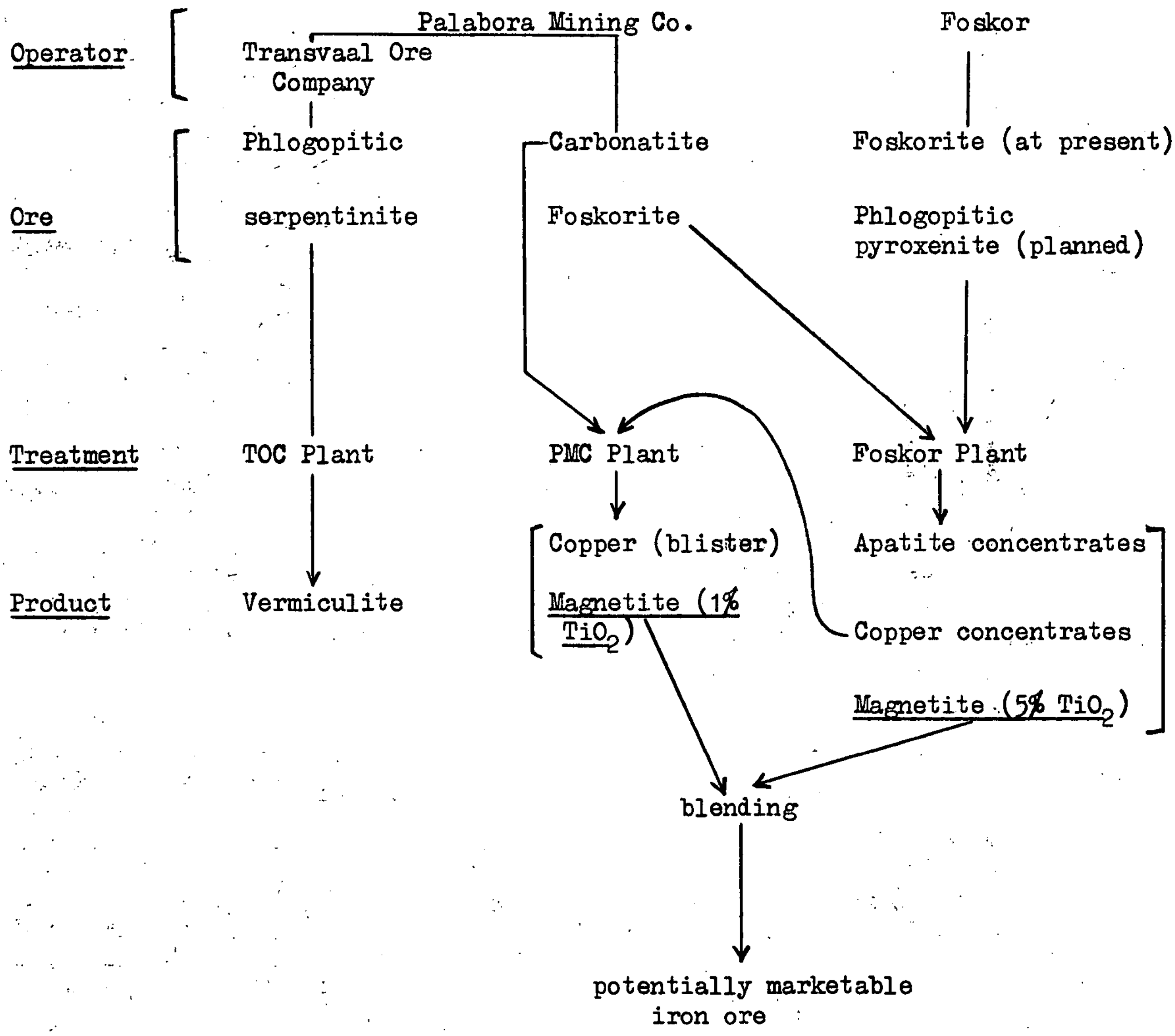
The deposits occur within a succession of banded ironstones, jaspers and shales which are equivalent to strata low in the Pretoria Series of the Transvaal. The beds crop out over a strike length of more than 250 miles from Preiska in the south to near the Botswana border in the north. Crocidolite mines are scattered along the entire zone of outcrop.

The asbestos deposits occur in up to four main stratigraphic zones. The lower zone is very consistent over the entire field but economic concentrations are patchy. The second zone and upper zones are of little economic importance but the third zone contains the Westernberg horizon, which, at the famous Koegas Mine consists of nine groups of asbestos seams with an aggregate thickness of 20 feet in a stratigraphic interval of about 110 feet. The asbestos is mined in bodies from 3 to 7 feet thick.

The origin of the deposits has been discussed by Du Toit (1945) who suggests that the fibre was generated during periods of crustal deformation by the transformation, in situ, of suitable iron-rich or soda-iron-rich layers in the banded ironstone sequence. More recent work suggests that the crocidolite was developed during lithification of beds of suitable composition, but that this only took place where these beds were in direct contact with layers of magnetite crystals. The mineralogy of amphibole asbestos has been discussed by Vermaas (1952).

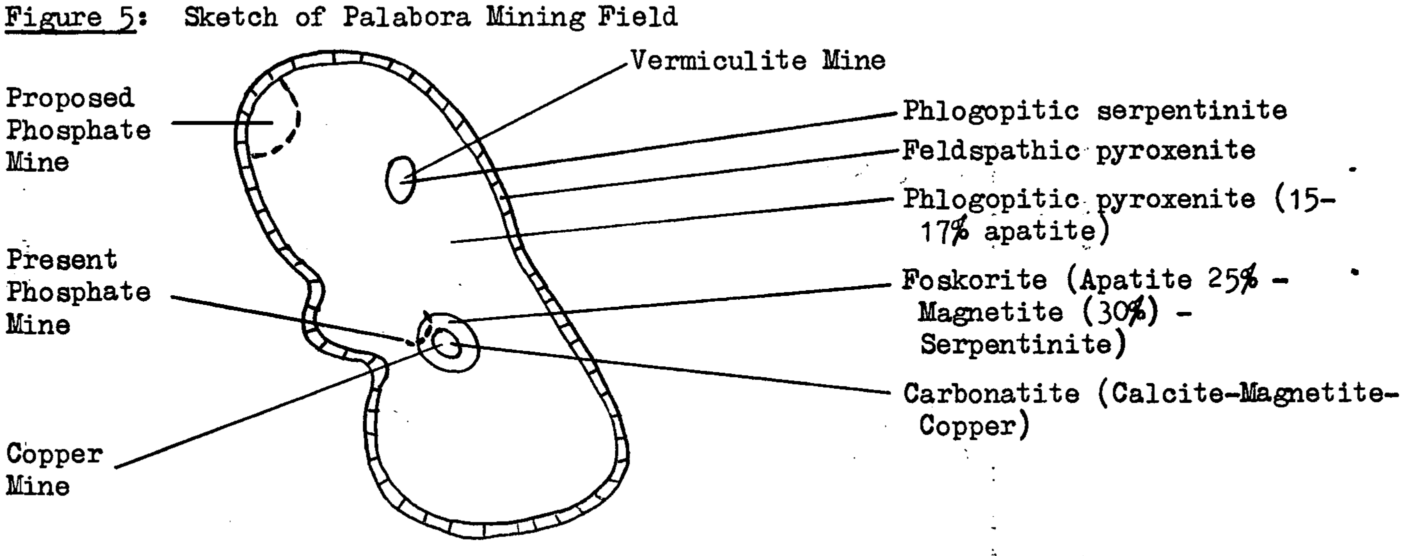
Palabora Copper, Phosphate and Vermiculite Mines: Palabora lies 200 miles north-east of Johannesburg, in the north-eastern Transvaal. Apart from supplying the bulk of South Africa's phosphate requirements and a substantial proportion of the world's vermiculite needs, the Palabora mines will shortly become a significant copper producer.

The copper occurrences at Palabora were known and worked by the pre-European inhabitants of the area, but it was not until the 1920's that geologists first became interested in them. Dr. Hans Merensky established that considerable reserves of phosphate were present in the area and a short-lived attempt to exploit phosphate minerals was made in the early 1930's. In 1951 the Government set up a company - FOSKOR - to exploit the phosphate deposits and this organization has grown rapidly. Vermiculite has been mined from the area for many years by the Transvaal Ore Company and copper mining has recently begun in preparation for the opening of a treatment plant; the copper is being mined by the Palabora Mining Company (PMC), in which Rio Tinto and American Metals Climax have an interest.



The ore bodies are associated with a pyroxenite-carbonatite intrusive complex. In broad terms the complex consists of a vertical pipe-like body of phlogopitic pyroxenite, elliptical in plan and some 8 square miles in area, which is itself intruded by separate carbonatite and serpentinite pipes (Fig. 5). The complex, which is about 2000 million years old (age determination and radiothorianite) intrudes gneissic granites believed to be older than 2500 million years.

Figure 5: Sketch of Palabora Mining Field



Copper: The carbonatite pipe which intrudes the phlogophitic pyroxenite mass consists essentially of coarsely crystalline calcite (70-75%) and magnetite (25-30%). The outer zone contains 0.5% Cu and the inner core 1% Cu, the overall grade being 0.7%. The pipe is about a quarter of a mile across and half a mile long; it has vertical walls. The PMC intends mining an area of 4000 feet by 5000 feet to a depth of 1200 feet by open cast methods. The operation will involve mining 320 million tons of copper ore which will be processed in the PMC plant and 320 million tons of foskorite and phogophitic pyroxenite of which part at least is to be processed by the FOSKOR plant. Although PMC's treatment plant is not yet open copper ore is being mined and stockpiled.

Chalcopyrite is the main ore mineral in the core of the carbonatite while bornite is dominant in the outer zone.

The deposit was proved by 130,000 feet of diamond drilling - in all 111 holes were sunk, the deepest being 3,500 feet. Some of the drilling was done from a test shaft.

The company plans to move 35,000 tons of copper ore and 35,000 tons of phosphate ore each day - i.e. about 25 million tons per annum from 20,000 feet of bench face using:-

6 Quarry masters
25 65-ton trucks
5 6-yard shovels
2 4½ yard shovels
1 12 yard shovel

Assuming full recovery the mining should yield about 90,000 tons of copper per annum. Production of magnetite from carbonatite at the PMC plant should run to about 4 million tons per annum.

Phosphate: The phosphate operations (controlled by FOSKOR) are at present based on open cast mining of the rim of the carbonatite pipe where "foskorite" (an apatite-magnetite-serpentinite) has developed. Apatite constitutes 25% of the rock and magnetite 30%. The magnetite contains about 5% TiO_2. Small, but extractable quantities of copper occur in the foskorite and interest is being shown in the possibility of recovering bedellierite (zirconium oxide) and associated hafnium from the ore. To permit mining of the adjacent carbonatite mass FOSKOR is shortly to abandon the mining of foskorite and begin open cast mining of phlogopitic pyroxenite which contains about 15% apatite (6% P_2O_5); the reserves of this ore are enormous - 3.9 million tons per vertical foot. The company envisages mining 350 million tons of ore during the next 70 years. The mining will proceed over a restricted area to a depth of 500 feet.

Current production of apatite concentrates (36% P_2O_5 content) is about 50,000 tons per month and copper concentrates 2,000 tons per month. About 1 million tons of magnetite are stockpiled each year.

Vermiculite: Vermiculite has been mined at Phalaborwa for a number of years by the Transvaal Ore Company, which is now a subsidiary of the Palabora Mining Company. The vermiculite is won from a pipe of phlogopitic serpentinite. The vermiculite occurs in a weathered zone from 80 to 100 feet deep. Two varieties of vermiculite occur, a dark, iron-rich variety derived from the hydration of biotite and a golden yellow vermiculite derived from the hydration of phlogopite. The latter is superior in quality; it occurs in "books" up to 6 or 8 inches across and up to 1" thick, and as scattered flake nests, pockets and large lenticular bodies. The expansion coefficient of this variety is twice that of the darker variety and expands up to 25 times that of its original size when heated.

Mining is by quarrying and the product is crushed and sieved into fine grades; the graded material is separated from waste by winnowing.

Production of vermiculite is currently running at about 12,000 tons per month.

<u>Bomvu Ridge Ironstone Mine</u>: The Bomvu Ridge iron deposit is located in the mountainous north-western part of Swaziland, 14 road miles to the north-west of Mbabane, the capital of the Protectorate.

The deposits were known and utilized by pre-European inhabitants of the area, but it was not until after World War II that the Geological Survey of Swaziland (Davies & Urie, 1957) proved the deposits to be of economic dimensions. In 1957 the Anglo-American Corporation of South Africa established a subsidiary company to further investigate, and mine the deposits (Bursill et al., 1964).

The ore bodies are associated with a tightly folded sequence of banded ironstones which form part of the Fig Tree Series of the Swaziland System. The bodies consist mainly of hematite and occur as enrichments within the banded ironstones. They are mined by open cost methods.

The bodies crop out over a strike length of 6500 feet. The maximum thickness is 320 feet and the dip is usually between 40° and 60°. The indicated reserves are 47.0 million tons of ore ranging in grade from 61.1% to 62.6% Fe. There are additional reserves at depth, in scree and in biscuity hematite which required beneficiation by screening.

A railway line was built at a cost of £A10 million to link the mine with the port of Lourenco Marques in Mozambique. It was opened to ore traffic in October 1964. The company has contracted to supply Japanese interests with $14\frac{1}{2}$ million tons of lump ore ($\frac{1}{4}$"-8") over a period of 10 years. Some 40% of the ore processed is too fine for sale and is being stockpiled.

<u>Selukwe Chromite Field</u>: Rhodesia produces about $\frac{1}{2}$ a million short tons of chromite per annum. The country has reserves of over 300 million tons of refactory and chemical grade material and reserves of over 300 million tons of metallurgical ore. About 540 million tons are in the Great Dyke. The principal chromite mining district is the Selukwe Field from where about 3/5th of the country's output is won; the field is worked by Rhodesia Chrome Mines Ltd., a wholly owned subsidiary of the Union Carbide Corporation.

Selukwe is about 100 miles north-east of Bulawayo and is near the geographic centre of Rhodesia. Chromite mining began in the area in 1905. The ore bodies are irregular, lenticular or rounded pods of massive chromite up to 400 feet long and 100 feet across and a few hundred feet in depth. They occur in serpentinite, talc schists and chlorite schists of the 'Basement Complex'. The bodies tend to occur in groups roughly parallel to one another and to the direction of foliation of the schists.

Quarrying and open-cut methods of mining were used initially but underground methods are now employed and the workings are now down to over 1000 feet below surface. Metallurgical and refactory grades of ore are produced.

<u>Broken Hill Lead-Zinc Mine</u>: The Broken Hill lead-zinc mine lies in central Zambia 86 road miles north of Lusaka. It is owned by a subsidiary of the Anglo American Corporation. The ore deposits were discovered in 1902 and were named after the Australian Broken Hill. With the advent of a railway from the south shipments of ore began in 1906. Metallurgical difficulties prevented the production of zinc from sulphide ores until an Imperial Smelter was set up in 1946.

There are three main ore bodies at Broken Hill and they originally cropped out as small hillocks of jasper-like 'zinc silicate' ore standing in otherwise featureless country.

The ore bodies occur as giant inclined pods cutting through dolomite of the Katanga Supergroup, in the 'core' of a plunging syncline. The ore bodies are elliptical in plan and consist of a core of sulphide ore (galena and sphalerite with minor pyrite) completely encased by a coat of oxidized ores which are mainly silicates, oxides and carbonates of zinc, lead and iron with subsidiary vanadium and copper. The sulphide ore averages about 23% lead, and 34% zinc and thus contains virtually no gangue. The 'silicate' ore averages 8% lead and 23% zinc and the mixed mill feed averages about 19% lead and 30% zinc.

The depth of oxidation of the ore (1500 feet) is puzzling and has been attributed to a lowering of the water table during the Tertiary; the present water table is only about 20 feet below the surface.

The mine is served by three shafts - a pumping and ventilation shaft, a large ore shaft 900 feet deep, and a smaller materials shaft. An internal sub-vertical shaft from the 850 foot to the 1250 foot level is also in commission. All shafts have been sunk in the footwall of the ore bodies and footwall haulages are driven parallel to the ore body. The mining method used is a modified shrinkage-slice and long hole method of stoping.

At the end of 1964 the ore reserves were estimated to be 5,542,000 short tons containing 13.1% lead and 26.6% zinc. In 1964 109,041 short tons of ore were milled to produce 13,117 long tons of lead, 46,020 long tons of zinc (98.5 - 99.95 Zn) 14 long tons of cadmium and 46,316 troy ounces of silver.

<u>Zambian Copperbelt</u>: Zambia produces about 15% of the worlds current copper output and has over one quarter of the worlds known copper reserves. The deposits in the Copperbelt were first recognized as being of major importance between 1926 and 1931 and since then over 10 million long tons of copper have been produced. Current output is more than 650,000 long tons of copper per annum.

Two companies - the Rhodesian Selection Trust and Rhodesian Anglo American Ltd - control the mining operations. Their respective interests are shown in Table 7.

Table 7: Mines of the Zambian Copperbelt - Ownership, year of opening and ore reserves (1960).

Mine	Owner	Opened	Ore Reserves (1960) -millions short tons	% Cu
Roan Antelope	RST	1931	94	3.04
Nkana (Rhokana)	Ang. Am	1932	120	3.07
Mufulira	RST	1933	179	3.35
Nchanga	Ang. Am	1939	179	4.65
Chibuluma	RST	1955	10	4.89
Bancroft	Ang. Am	1959	101	3.69
Chambishi	RST	1965	35	3.37
Babuba	RST	Potential	112	2.41
Bwana Mkubwa	Ang. Am	Closed 1931	2	3.94
			833	3.50

The ore deposits occur in the lower part of the Roan Group, the basal part of an Adelaidean succession known as the Katanga Supergroup (Reeve, 1963). There is considerable lateral lithological variation within the lower Roan Group and its thickness is also variable. The lowermost beds consist of conglomerates and arkoses, generally capped by aeolian quartzites from 50 to several hundred feet thick. The latter commonly form a footwall to the ore beds. The ore beds consist of argillite and impure dolomite and although remarkably persistant they are of course, only locally of ore grade. Beds of cross-bedded quartzite, argillite and dolomite overlie the ore-bearing strata.

Much has been written on the genesis of the deposits and although the weight of evidence favours a syngenetic origin, several alternative hypotheses have been put forward.

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