ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
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THE GEOLOGICAL EVOLUTION OF THE PRIMITIVE EARTH : EVIDENCE FROM THE BARBERTON MOUNTAIN LAND

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by

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"The Barberton Mountain Land offers the geologist a unique opportunity to study early stages in the evolution of the earth. There, in southeast Africa, remnants of the oldest upper mantle, oceanic crust, and an overlying island-arc-like rock complex are fossilized in a sea of granite and granitic gneiss some 2.9-3.3 aeons (10^9 years) old. Studies of these rocks offer deep insight into many aspects of terrestrial differentiation, especially the early evolution of oceanic and continental crusts, the seas, and the atmosphere" - Engel (1970).

* *

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THE GEOLOGICAL EVOLUTION OF THE PRIMITIVE EARTH : EVIDENCE FROM THE BARBERTON MOUNTAIN LAND

INTRODUCTION

Close on 60 years have elapsed since the publication of A.L. Hall's (1918) memoir on the Barberton Mountain Land, which provided the first, comprehensive account of this unique geological area. In 1956, a further significant contribution to the geology of the region, as a whole, was made through the publication, by the Geological Survey of South Africa, of a map and accompanying explanation of the geology (Visser et al., 1956). Renewed interest in the Barberton area commenced in the early 1960's, when the Economic Geology Research Unit of the University of the Witwatersrand initiated investigations aimed primarily at assisting the local mining industry in its quest for gold mineralization. This involvement led to an on-going programme of research, during which selective studies, including those connected with the International Upper Mantle and Geodynamics Projects, have provided new insight into one of the Earth's classic regions of Archean geology.

The Southern African subcontinent is particularly suitable for the study of early Archean (> 3 400 m.y.) granite-greenstone terranes, but few areas, if any, are as old, well-developed, well-preserved, well-exposed, and sequentially ordered as the Barberton Mountain Land. Much has already been written about the region. Selected publications dealing with aspects of the stratigraphy include those of Anhaeusser et al. (1968), Anhaeusser (1969a, 1971a, 1971b, 1972, 1973a), Condie et al. (1970), Viljoen and Viljoen (1969a, 1969b, 1970a, 1970b, 1971), and Visser et al. (1956). Contributions dealing with granitic rocks include those of Anhaeusser (1966, 1969a, 1975b), Engel (1970), Hunter (1957, 1961, 1970, 1973, 1974), Roering (1967), Viljoen and Viljoen (1969c, 1969d), and Visser et al. (1956). Comprehensive summaries of the main features of investigations in the Barberton Mountain Land and the adjoining territory of Swaziland have been provided by Anhaeusser et al. (1968, 1969), Anhaeusser (1971a, 1973a), Hunter (1974), and Viljoen and Viljoen (1970a).

It is the intention in this review to emphasize some of the more important aspects that have emerged from the Barberton studies, and to attempt an evaluation of the significance of the observations in terms of models relating to the evolution of the Earth.

SWAZILAND SUPERGROUP

The Barberton Mountain Land is made up of two dominant components -- the Barberton greenstone belt and the surrounding granites. The greenstone belt comprises a wide variety of volcanic, igneous, and sedimentary rock-types, collectively labelled the Swaziland Supergroup, which, in turn, is composed of three major subdivisions that are, in ascending order, the Onverwacht, Fig Tree, and Moodies groups.

The Onverwacht Group, at the base of the sequence, attains a thickness of approximately 15 km, and has been subdivided by Viljoen and Viljoen (1969d) into six formations (see Figure 1). The lower three formations constitute the Tjakastad Sub-Group, comprising an approximately 7 km-thick succession characterized by abundant pillowed and massive flows and sills of peridotite and basalt, together with very subordinate quantities of interlayered, often aluminous, felsic pyroclastic material (tuffs and agglomerates). Discontinuous bands and lenses of carbonaceous shaly chert, banded chert, banded iron-formation (magnetite-quartz-amphibole rocks), and calc-silicate rocks (quartz-diopside-plagioclase-garnet assemblages) have been recorded from various parts of the succession, which is also referred to as the lower *ultramafic-mafic unit* (Anhaeusser and Viljoen, 1965; Anhaeusser, 1972, 1973b; Viljoen and Viljoen, 1969a). In addition, small intrusive bodies of Na-rich quartz-feldspar porphyry occur in the Komati Formation of the sub-group (Anhaeusser, 1969a, 1972; Viljoen and Viljoen, 1969a).

A persistent sedimentary horizon, termed the Middle Marker (Viljoen and Viljoen, 1969b), occurs at the top of the Tjakastad Sub-Group, and heralds an abrupt change in the nature of the volcanicity occurring in the upper three formations (Geluk Sub-Group) of the Onverwacht stratigraphy. Also collectively known as the *mafic-felsic unit*, the upper formations are represented by a typically calc-alkaline igneous series of lavas consisting of cyclically alternating mafic and intermediate-to-acid volcanics, together with a wide variety of pyroclastic rocks. Individual volcanic cycles usually commence with wide zones of tholeiitic basalt, which are generally overlain

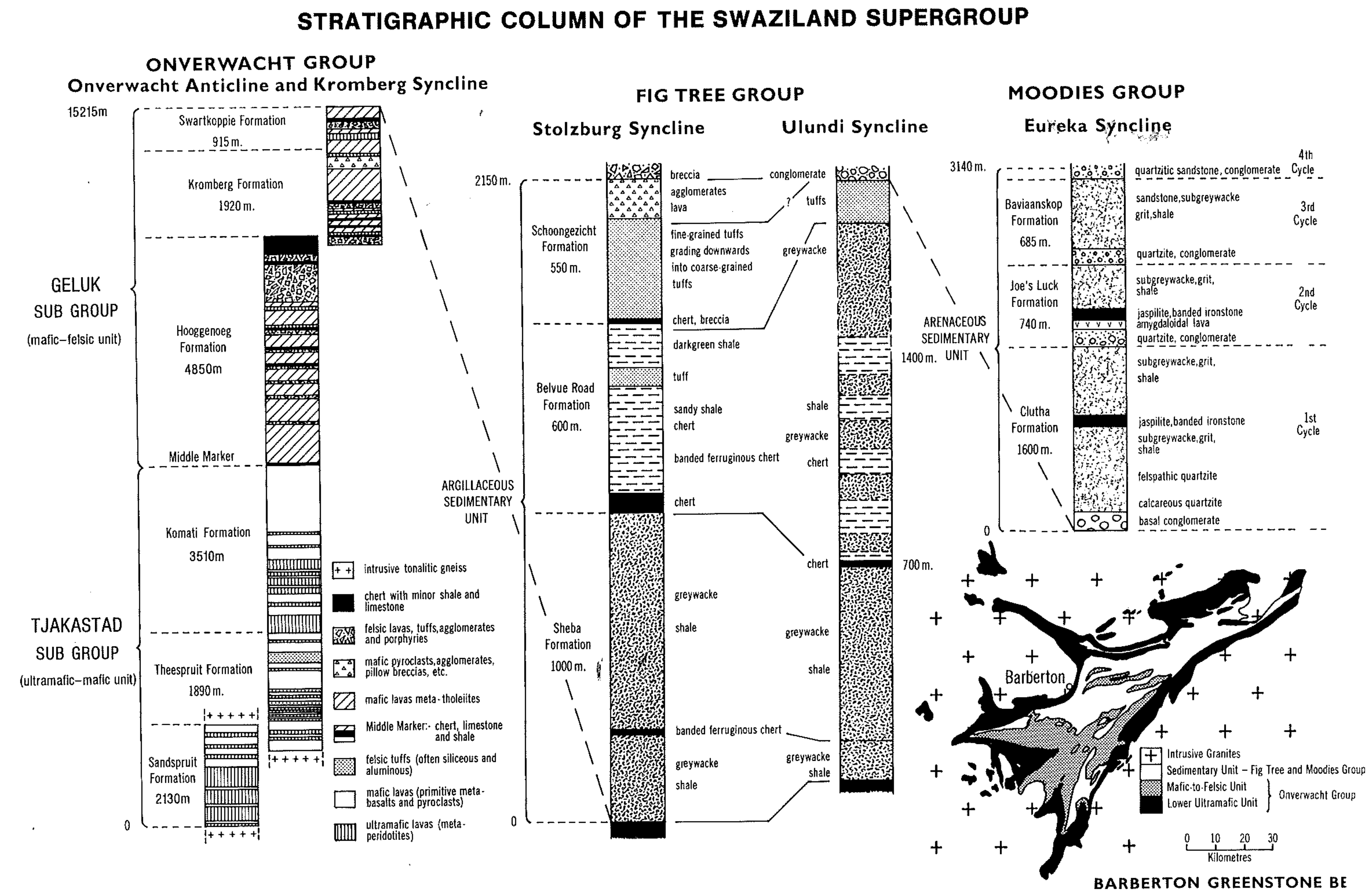


Figure 1 : *Stratigraphic sections depicting the stratigraphy of the Swaziland Supergroup in the Barberton Mountain Land, South Africa. The inset general geological map of the Barberton greenstone belt shows the distribution of the lower ultramafic-mafic unit, the mafic-felsic unit, and the sedimentary units (after Anhaeusser, 1973a - reproduced by permission of the Phil. Trans., Royal Society, London).*

by thinner zones of dacitic-to-rhyodacitic lavas. These felsic lavas are commonly capped by pyroclastic units and banded cherts, some attaining thicknesses of up to 180 m (Viljoen and Viljoen, 1969b). Interlayered with the massive and pillowed lavas, pillow breccias, agglomerates, and tuffs, are subordinate ultramafic bands and lenses, as well as chemical sedimentary units (banded carbonaceous shales and cherts and sideritic carbonate beds), aquagene tuffs, and pelagic carbonate-chlorite sediments. Associated with some of the felsic volcanics are consanguineous intrusive bodies of quartz-feldspar porphyry (granodiorite-quartz diorite-quartz monzonite).

Although most of the ultramafic and mafic rocks in the Onverwacht succession are subaqueous lava flows, a number of plutonic, sill-like, differentiated bodies are also developed at various stratigraphic levels throughout the column. The majority of these are layered ultramafic-mafic complexes, and are most common in the Tjakastad Sub-Group, where they are considered to represent igneous masses developed penecontemporaneously with the surrounding peridotitic and basaltic lavas (Anhaeusser, 1969a, 1973b, 1974b; Viljoen and Viljoen, 1970b).

Overlying the predominantly volcanic successions of the Onverwacht Group is an assemblage comprised mainly of detrital sediments, with subordinate volcanic and pyroclastic members. This succession has been subdivided into an argillaceous sedimentary unit known as the Fig Tree Group, and an arenaceous sedimentary unit referred to as the Moodies Group (Figure 1). These stratigraphic units display disconformable, as well as unconformable, relations with each other and with the Onverwacht Group. The Fig Tree assemblage consists mainly of greywackes and shales, together with siliceous chemical precipitates (banded cherts, banded ferruginous cherts) and minor trachy-andesitic lavas, agglomerates, and tuffs (Condie et al., 1970; Reimer, 1967, 1973; Visser et al., 1956). The Fig Tree Group, which attains a thickness of 2-3 km, has been subdivided into three formations (Figure 1). The Moodies Group at the top of the Swaziland succession attains a thickness approaching 4 km (Visser et al., 1956), and has its most complete development in the Eureka Syncline (Figure 1). Also subdivided into three formations, the Moodies Group represents a cyclically repetitive assemblage composed predominantly of conglomerates, quartzites, sub-greywackes, sandstones, and shales, together with minor volcanic horizons, jaspilite, and banded iron-formation (Anhaeusser, 1969a; Visser et al., 1956).

PRIMITIVE KOMATIITIC MAGMAS

The basal stratigraphy of the Barberton greenstone belt (Tjakastad Sub-Group) is characterized by large thicknesses of mafic and ultramafic lavas. Viljoen and Viljoen (1969a) demonstrated the geochemical uniqueness of these rocks, and proposed the name komatiite for both peridotitic and basaltic varieties. For the basalts, a further three types were distinguished, basing the subdivision mainly on the variability of the magnesian content of the rocks (Barberton-type ∿ 10% MgO; Badplaas-type ∿ 15% MgO; Geluk-type ∿ 20% MgO).

The ultramafic and mafic komatiites possess a distinctive major element geochemistry, having high MgO contents, low alkalis (particularly K_2O), and high CaO/Al_2O_3 ratios (Viljoen and Viljoen, 1969a). Brooks and Hart (1974) consider that the diagnostic chemical features of komatiites require more rigorous definition, because there is a danger that numerous other rocks, classified as picrites, oceanites, and ankaramites (especially from oceanic islands), could be termed komatiites as well. Their scheme to chemically distinguish the basaltic komatiites is as follows :

SiO_2		46-53 per cent
CaO/Al_2O_3	:	> 1 per cent
TiO_2	:	< 0,9 per cent
K_2O	:	< 0,9 per cent (in general, basaltic komatiite has K_2O < 0,5 per cent)
MgO	:	> 9 per cent

Following the Barberton discovery, several other reports of komatiitic basalts and peridotites have been made from Archean greenstone terranes in Canada (Brooks and Hart, 1972; Pyke et al., 1973), Western Australia (Nesbitt, 1971), and India (Naqvi, 1971). Peridotitic komatiites are at present unknown from modern environments, and basaltic komatiites are extremely rare.

Since their recognition, the petrogenetic aspects of komatiites have received a great deal of attention. Because of the association of basaltic komatiite with a basalt-andesite-dacite-rhyolite volcanic suite in the Canadian Archean, Brooks and Hart (1972), at first, thought that these rocks should be related genetically to an island-arc tectonic setting. As an initial model, they proposed that the various mafic rocks are all simply the result of different degrees of partial melting of a sub-arc mantle. Archean tholeiites, it was argued (Hart et al., 1970), represent fairly high degrees of mantle-melting at shallow depths. Basaltic komatiites would represent even more extensive melting (especially of clinopyroxene components), and the peridotitic komatiites might represent almost total melts of the mantle. Evidence that the peridotitic komatiites once represented ultramafic liquids, extruded as fluid magmas in an aqueous environment, was first provided by Viljoen and Viljoen (1969a), and experimental studies (Green, 1972a; Green et al., 1975) suggested that the temperature of extrusion of such rocks, which approach the pyrolite-model compositions of the upper mantle, was 1 650° ± 20°C. The experimental studies further suggested that the peridotitic komatiite could have been derived from a substantial degree of melting (60-80%) of pyrolite, whereas the basaltic komatiite could have come from a lower degree ($\sim$ 40%). The high extrusion temperature obtained by Green et al. (1975) for the Barberton peridotitic komatiite led to the suggestion that this magma had been diapirically emplaced from a depth of at least 200 km (Green, 1975). Earlier, the high degree of mantle melting prompted Green (1972a, 1972b) to suggest a catastrophic, rapid magma genesis, and it was postulated that greenstone belts represent altered equivalents of lunar maria, forming as a result of major impacts triggering partial melting at depths of 150-300 km. Preliminary experimental studies carried out recently by J.R. McIver (personal communication, 1975) suggest that the temperature of 1 650°C obtained by Green et al. (1975), for completely liquid peridotitic magma, may be as much as 200°C too high. The peridotite sample studied by Green and his co-workers was found by McIver and Lenthall (1974) to plot in a position similar to ultramafic rocks, believed to have been enriched in olivine by crystal settling at depth, and which reached the surface in the form of a magma carrying olivine phenocrysts or microphenocrysts. These would have had the effect of increasing the temperature necessary for complete melting.

In an attempt to explain aspects of the komatiite geochemistry, Green (1975) developed models of magma genesis, in which selective removal of garnet during ascent produces $CaO/Al_2O_3 > 1$ and heavy rare-earth element depletion in the resulting ultramafic and mafic extrusions. Cawthorn and Strong (1974) argued differently, suggesting that, if the upper mantle possessed a mineralogical layering with a greater ratio of clinopyroxene to garnet (i.e. high CaO/Al_2O_3 ratio) at comparatively shallow depths, shallow-depth melting could produce komatiitic liquids with a high CaO/Al_2O_3 ratio.

McIver and Lenthall (1974), in considering the phase relationships of the lower Onverwacht mafic and ultramafic extrusives in terms of the CMAS system of O'Hara (1968), postulated that the parental magma of the Tjakastad volcanic pile had a composition close to that of the ultramafic rocks occurring in the lowermost Sandspruit Formation. It was concluded that the development of this parental magma could satisfactorily be accounted for by partial melting of a four-phase lherzolite mantle at depths of 90-100 km or more. Their proposal that the mafic and ultramafic komatiite-type extrusives and associated tholeiitic basalts, occurring stratigraphically above the Sandspruit Formation, developed mainly as a result of polybaric olivine and orthopyroxene fractionation from Sandspruit-type magma may prove incorrect, as continuing geochemical studies (S. Smith, personal communication, 1975) suggest that the compositional differences, noted by Viljoen and Viljoen (1969a), between the Sandspruit- and Komati-formation ultramafics appear no longer to be statistically valid.

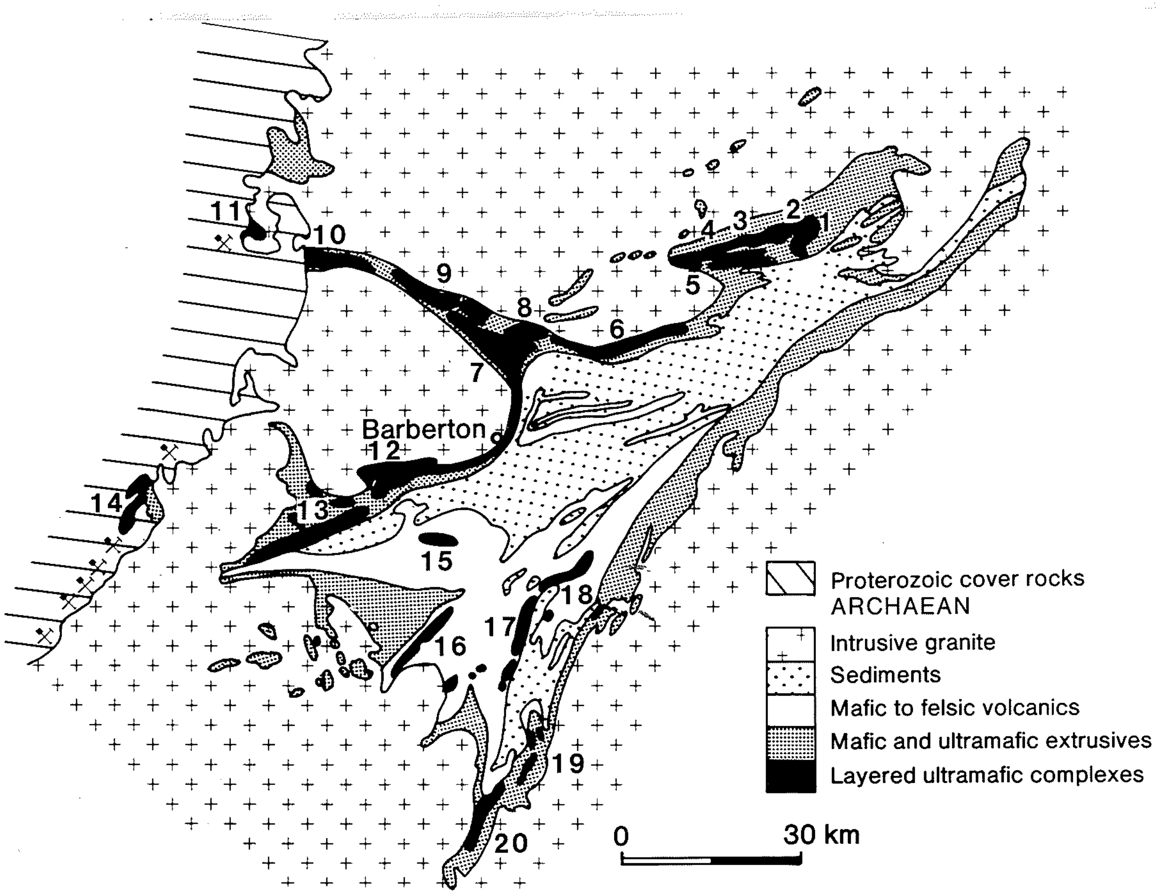
Commenting on the significance of komatiites, Brooks and Hart (1974) maintained that neither the peridotitic nor the basaltic variety is a reliable tectonic-province indicator. The fact that the komatiites generally are accompanied by low-K tholeiites, that are now known to occur in almost every modern tectonic environment (Jamieson and Clarke, 1970), contributes significantly to this viewpoint. Despite objections, however, it would appear that support continues for equating the komatiitic lavas with modern oceanic crust. The subaqueous volcanism, the distinctive geochemistry, and the nature of the stratigraphy of the lower Onverwacht formations in the Barberton greenstone belt have reaffirmed this analogy. The komatiite basalts have, furthermore, yielded exceptionally low initial Sr^{87}/Sr^{86} ratios ($\sim$ .700), suggesting an equivalence of these rock-types with similar assemblages formed at modern oceanic ridges (Allsopp et al., 1973; Jahn and Shih, 1974).

Rare occurrences of komatiitic peridotite and basalt are associated with calc-alkaline basalt-dacite-rhyodacite assemblages of the Geluk Sub-Group in the Barberton greenstone belt. This part of the Onverwacht volcanic pile, as with the case in the Canadian Archean mentioned by Brooks and Hart (1972), has been regarded as analogous to an island arc succession (Anhaeusser, 1973a; Engel, 1970; Viljoen and Viljoen, 1969b). The absence, however, of the calc-alkaline rock-association in the Tjakastad Sub-Group sets this assemblage apart, and the predominantly peridotitic and basaltic komatiite sequence does, it is suggested, signify some association with a particular tectonic regime (i.e. oceanic).

The nature of komatiites and their general absence in post-Archean times has led to the suggestion that Archean geothermal gradients were two or three times greater than those at present (Brooks and Hart, 1972, 1974; Fyfe, 1973; Green, 1975).

LAYERED ULTRAMAFIC COMPLEXES

In several localities within the Tjakastad Sub-Group and, to a lesser extent, in the Geluk Sub-Group, there occur a number of layered differentiated ultramafic complexes, in many of which chrysotile asbestos fibre of economic significance is found. Most of the layered complexes are situated on the northwest flank of the Barberton greenstone belt (Figure 2), where they occur as sills or discontinuous pods that were intruded penecontemporaneously with the ultramafic and mafic



LAYERED ULTRAMAFIC COMPLEXES

1	KOEDOE	11	ELANDSHOEK
2	MAGNESITE	12	HILVERSUM
3	CENTRAL-CANAL	13	STOLZBURG
4	SHIP HILL	14	KALKKLOOF
5	BUDD	15	GRANVILLE GROVE
6	SUGDEN	16	ROSENTUIN
7	HANDSUP	17	MSAULI
8	MUNDT'S CONCESSION	18	HAVELOCK
9	HILLSIDE	19	FORBES REEF
10	KAAPSEHOOP	20	MOTJANE

Figure 2 : *Geological map of the Barberton greenstone belt, showing the distribution of the layered differentiated ultramafic complexes in the Onverwacht volcanic sequence.*

lavas. The layered complexes associated with the mafic-to-felsic assemblages of the Geluk Sub-Group are fewer in number, and are smaller, volumetrically, than their counterparts lower in the stratigraphy. Not much is known of these occurrences, although two of the complexes (Msauli and Havelock) are hosts to large chrysotile asbestos deposits, the latter rivalling the major ore deposits at Shabani and Mashaba in Rhodesia (Anhaeusser, 1974b; Laubscher, 1968).

Geologically, the layered complexes generally consist of cyclic repetitions of dunites, harzburgites, peridotites, pyroxenites, gabbros, norites, and anorthosites (Anhaeusser, 1969a, 1973b, 1974b; Viljoen and Viljoen, 1970b). Invariably, the lower members of the layered sequences consist of alternating serpentinized dunite (olivine cumulates) and orthopyroxenite layers (bronzite cumulates). The upper layers comprise mainly serpentinized harzburgites and peridotites, ortho- and clinopyroxenites, gabbros, norites, and gabbroic anorthosites. The olivine or olivine-orthopyroxene cumulate rocks found at the base of the layered complexes are the most favourable ultramafic host-rocks for chrysotile fibre development. Where fractional crystallization of the primary magma was most efficient, cumulus minerals settled out rapidly, causing monomineralic phases to develop. These minerals, in the lower cumulate layers, attained a high degree of purity, the olivines and orthopyroxenes being magnesium-enriched fosterites and bronzites or enstatites.

The Tjakastad layered complexes are of particular interest in that the parental magmas from which they were derived were peridotitic in composition (Anhaeusser, 1969a, 1974b; Viljoen and Viljoen, 1970b). This is in marked contrast to the basaltic (tholeiitic) magma-types responsible for the large differentiated gabbroic layered intrusions like Stillwater, the Bushveld Complex, Skaergaard, and many others.

CHEMICAL SEDIMENTS

The earliest sediments, found throughout the Onverwacht volcanic pile, consists almost exclusively of chemical precipitates (cherts, iron-formations, minor carbonates) and volcanogenic debris (tuffs, agglomerates). Evidence of incipient detrital sedimentation first appears in the Fig Tree succession, where greywacke-shale assemblages constitute the earliest clastic sediments, being derived from the erosion of pre-existing Onverwacht rocks and an evolving sialic crustal component (Anhaeusser, 1973a). The most prominent chemical sediments are the banded siliceous and carbonaceous cherts and banded iron-formations. Less common, or rare in the Barberton greenstone belt, are carbonate rocks (dolomite, limestone) and stratiform sulphate occurrences (barite). Discontinuous, impure carbonate sediments occur erratically throughout the Swaziland Supergroup, being most evident in the volcanic successions, where they generally exist as calc-silicate hornfelses or schists (Anhaeusser, 1973b; Anhaeusser and Viljoen, 1965). Stratiform occurrences of barite occur in both the Onverwacht and Fig Tree groups, and are considered to be of volcano-genic origin (Viljoen and Viljoen, 1969e; Reimer and Heinrich, 1975). Few details are known of the chemical sediments in the Barberton greenstone belt, although it is possible to identify four varieties of iron-formation (oxide, carbonate, silicate, and sulphide facies), and to outline their characteristics and mode of development.

One of the most noteworthy features of the Swaziland Supergroup is the cyclical nature of the volcanism and, to a lesser extent, that of the sedimentation (Anhaeusser, 1971b; Viljoen and Viljoen, 1971). In the Tjakastad Sub-Group, felsic tuffs and banded chert layers or lenses in places terminate minor cycles of peridotitic and basaltic volcanism. The cherts may be carbonaceous, siliceous, or, in some cases, banded ferruginous cherts. The last-mentioned can be regarded as silicate-facies iron-formation, as they consist of banded quartz-grunerite rocks when metamorphosed (Anhaeusser, 1963, 1973b; Viljeon and Viljoen, 1970b; Visser et al., 1956). Also intimately interlayered with the komatiitic basalts are banded quartz-magnetite-amphibole rocks (mixed oxide- and silicate-facies iron-formation). In the Barberton belt, these are poorly developed, and appear to represent proto-iron-formations. In Rhodesian greenstone belts, however, banded iron-formations, associated with the ultramafic-mafic successions of the Sebakwian Group, are well-represented (Beukes, 1973). Higher in the Barberton stratigraphic column (Geluk Sub-Group), cyclic volcanism is particularly well-developed (Viljoen and Viljoen, 1969b). Banded siliceous and carbonaceous cherts terminate the cycles which gradually give way upwards to banded ferruginous cherts and banded iron-formations in the Hooggenoeg Formation. In the Kromberg Formation, prominent banded carbonaceous cherts and shales are interlayered with the mafic-felsic volcanics. No oxide-facies iron-formations are developed, but narrow bands of siderite (carbonate-facies iron-formation) appear locally. In the Swartkoppie Formation, at the top of the Onverwacht succession, a stratiform sulphide band, consisting of massive, as well as disseminated, layers of pyrite occurs, intercalated with banded cherts (van Vuuren, 1964). The sulphide band, considered to be syngenetic, may represent a volcanogenic exhalative (fumarolic) sulphide-facies iron-formation interlayer.

In the Fig Tree Group, cherts and banded iron-formations are interbedded with shales and greywackes (Beukes, 1973; van Vuuren, 1964; Visser et al., 1956). The ferruginous cherts and iron-formations are generally non-magnetic (hematite subfacies), and, in places, have undergone leaching of the silica-rich bands to form white porcelaneous or chalky layers. Supergene enrichment of these iron-formations has led to the development of iron-ore deposits, as at the Ngwenya Mine in Swaziland (Bursill et al., 1964).

In the Moodies Group, at least three cycles of sedimentation have been recognized (Anhaeusser, 1971b, 1974c). Each cycle begins with conglomerates and quartzites, which grade upwards into an assortment of shales, sub-greywackes, and sandstones. Magnetite-rich shale zones, with jasper bands, are present in the first and second cycles (Figure 1), whereas magnetic shales without jaspilites occur in the third cycle.

LITHIC PROPORTIONS

The broad lithologic proportions of the Swaziland Supergroup in the Barberton greenstone belt have been calculated by Anhaeusser (1974a), and are depicted in Figure 3. Peridotites and

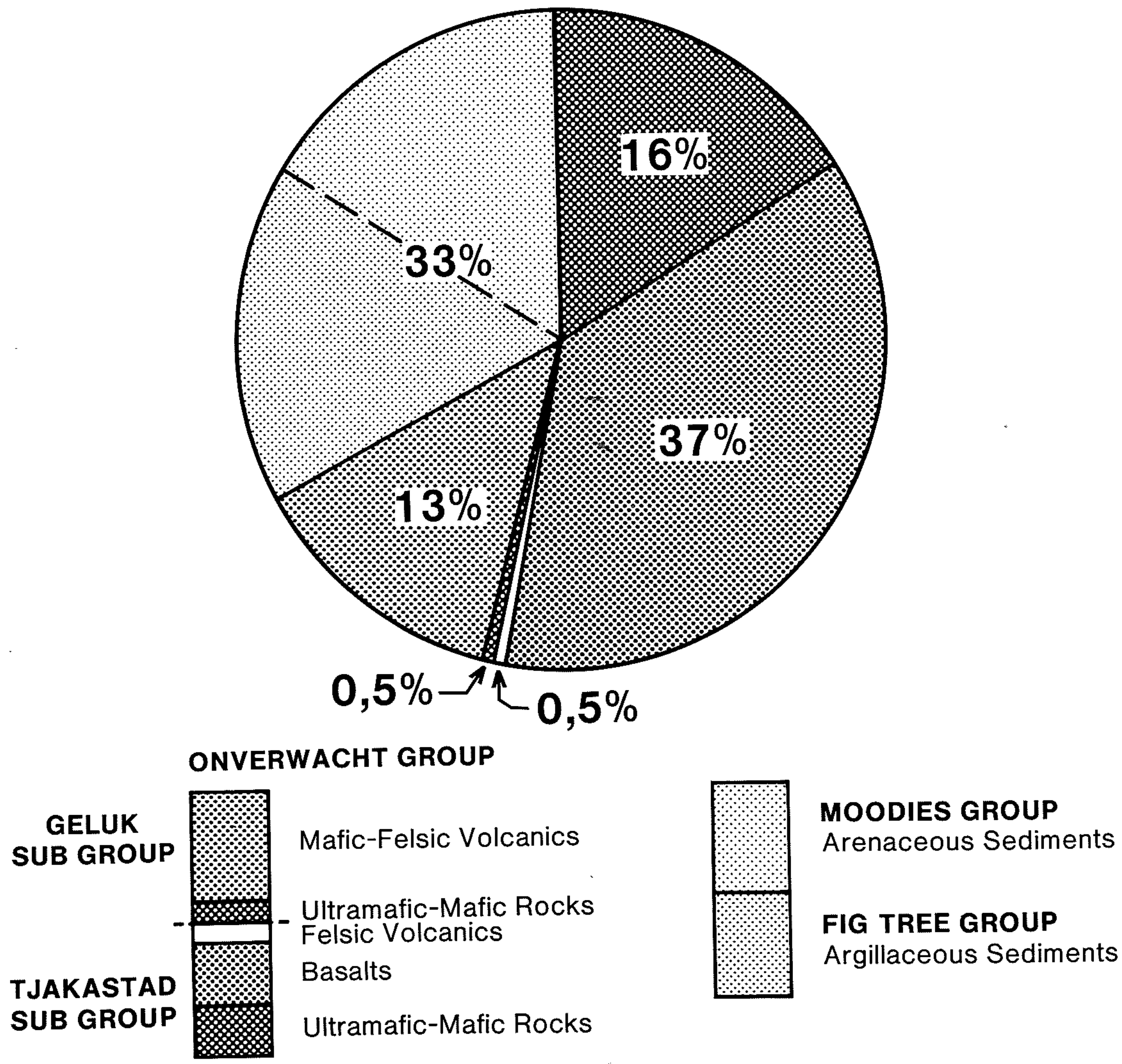


Figure 3 : Diagram depicting the lithic proportions of the main rock-types in the Swaziland Supergroup, Barberton greenstone belt.

basalts, particularly of the komatiitic variety, make up the bulk of the Tjakastad Sub-Group. The amount, which approaches close to 53 per cent, includes the contributions made to the total by the layered differentiated ultramafic complexes. Furthermore, it is evident from Figure 3 that felsic volcanics are, volumetrically, insignificant in the lower formation (0,5%), a feature not fully appreciated due to the prominence these rocks receive because of their usefulness as stratigraphic marker beds. Similarly, ultramafic-mafic rocks of the type found in the Tjakastad succession are subordinate components (0,5%) of the Geluk Sub-Group. The latter assemblage comprises approximately 13 per cent of the total greenstone belt lithology, and is dominated by cyclically developed volcanic rocks possessing calc-alkaline chemical affinities.

The Fig Tree and Moodies successions together make up approximately 33 per cent of the lithic component of the Barberton greenstone belt, this amount being almost equally divided between the two groups. Volumetric proportions of the volcanic component in these two groups are difficult to establish, but would probably be less than three per cent.

The Swaziland Supergroup in the Barberton greenstone belt thus consists of approximately two-thirds volcanic rocks and one-third sediments. Of the volcanic component, an anomalously high proportion consists of primitive komatiitic basalts and peridotites (including the layered ultramafic complexes), all of which represent, according to Engel (1970), a "Moho-oceanic crust complex", more completely developed and preserved than at the base of any analogous Archean greenstone belt so far found in the world.

GRANITES

No generally acceptable classification of the great variety of granitic rock-types surrounding the Barberton greenstone belt has yet been formulated. The position is likely to remain this way until the contentious issues relating to the nature of the primitive crust in the region can be satisfactorily resolved. At present there are two opposing points of view. The one most favoured thus far is that the ancient greenstone belts of the shield areas were initially laid down on a sialic crust. In Southern Africa, the chief proponents of this concept are Hunter (1970, 1973, 1974) and Stowe (1968a, 1968b), both of whom envisage a complex assortment of gneisses, migmatites, and accompanying metamorphites as constituting a floor to the supracrustal greenstone belt lithologies. The second school of thought envisages that the primitive komatiitic basalts and peridotite volcanics, found at the bases of Southern African greenstone belts, as well as of many greenstone piles elsewhere, represent lavas developed on a primordial upper mantle, prior to the evolution of any sialic crust in these regions. The main arguments for this assertion have been expressed by Anhaeusser (1973a, 1975a) and Viljoen and Viljoen (1969d, 1970a). Engel (1970) is also of the opinion that the basal parts of the Swaziland Supergroup were strikingly like contemporary oceanic crust. He considered that the peridotite flows and thick differentiated ultramafic sills were interlayered with basalts "in relations and proportions suggestive of a fossil oceanic Moho, and an uppermost mantle of the earth preserved for some 3,4 aeons (10^9 years)".

The opposing classifications of the granitic rocks surrounding the Barberton greenstone belt in Swaziland and the eastern Transvaal are listed below :

Viljoen and Viljoen (1969c)		Hunter (1973)	
D.	young plutons	6.	granite plutons
C.	Nelspruit gneisses and migmatites	5.	homogeneous hood granites
B.	homogeneous hood granites	4.	Nelspruit gneisses and migmatites
A.	ancient tonalitic gneisses	3.	tonalite gneiss domes
		2.	Granodiorite Suite
		1.	Ancient Gneiss Complex

In the Transvaal, the ancient tonalitic gneisses include a wide variety of biotite- and hornblende-bearing tonalitic granites and gneisses, passing locally into trondhjemitic, dioritic, granodioritic, and quartz-dioritic equivalents, and including a variety of metamorphosed xenoliths, the latter derived from the fragmentation of greenstone belts. Included in this category of granites are diapiric plutons emplaced around the northwestern and southern margins of the Barberton greenstone belt 3,22-3,31 ± 0,04 b.y. ago (Oosthuyzen, 1970), and which are responsible for the superimposed structural deformations in these areas (Anhaeusser, 1969a, 1971a, 1975a; Viljoen and Viljoen, 1969c, 1969d). The overall similarities (including major element geochemistry, texture, and petrology) of the ancient tonalitic gneisses, and their inclusions, with rocks classed with the Ancient Gneiss Complex by Hunter (1970, 1973) have been described at length by Anhaeusser (1973a) and Viljoen and Viljoen (1969c, 1969d). Hunter (1974) still firmly adheres to the view, however, that the rocks of the Ancient Gneiss Complex form part of an earlier granitic cycle, consisting of two main types : (1) a bimodal association of interlayered leuco-tonalitic gneisses and amphibolites, and (2) metamorphites that include quartzites, quartzo-feldspathic gneisses, siliceous and biotite-rich garnetiferous gneisses, quartz-diopside and diopside-plagioclase granulites, quartz-magnetite-grunerite gneisses, banded iron-formation, and biotite-hornblende gneisses. As pointed out earlier, the basal members of the Swaziland Supergroup (Tjakastad Sub-Group) accommodate all the lithological varieties that constitute the metamorphites of the Ancient Gneiss Complex. In the opinion of Anhaeusser (1973a) and Viljoen (1969c) these rocks have remained as resistors to the processes of intrusion, assimilation, and granitization that accompanied the destruction of the lateral (and basal) equivalents of the Barberton greenstone belt stratigraphy in Swaziland and elsewhere on the Kaapvaal craton. Furthermore, geochronological studies (Davies, 1971; Oosthuyzen, 1970) have so far demonstrated that the ancient tonalitic gneisses of the eastern Transvaal are indistinguishable from their proposed counterparts in the Ancient Gneiss Complex of Swaziland. The age of approximately 3,34 b.y. obtained by Davies (1971) for the Ancient Gneiss Complex is also younger than the 3,50 ± 0,2 b.y.-old Rb-Sr age ascribed to basaltic komatiites from the Tjakastad Sub-Group by Jahn and Shih (1974). The geochronological data presently available therefore lend support to conclusions that rocks of granitic composition evolved at a stage later than the primitive basal units of the Barberton greenstone belt.

The Granodiorite Suite (Hunter, 1973, 1974) comprises an assemblage of coarse-grained plutonic rocks ranging in composition from ultramafic to acid. Petrologically, chemically, and geochronologically, rocks of the Granodiorite Suite bear a close similarity to those found in the Ancient Gneiss Complex, and Viljoen and Viljoen (1969c) considered that there were adequate grounds for including them within the category of ancient tonalitic gneisses. Hunter (1974) maintained, however, that no equivalents of this suite have been recognized in the Transvaal, and that intrusive contacts with the Ancient Gneiss Complex, the lack of strong foliation, and the presence of quartz diorite and more mafic rock-types combine to distinguish this group of rocks from both the Ancient Gneiss Complex and the diapiric plutons.

In addition to the ancient tonalitic gneiss varieties, the granites in the eastern Transvaal and Swaziland have been subdivided into categories which reflect a wide range of compositional, textural, and field relationships. To the north of the Barberton greenstone belt, the Nelspruit migmatite gneiss terrane consists of a complex assemblage of gneisses, migmatites, homogeneous and nebulitic granodiorites, adamellites, and pegmatites, ranging in age between 3,16 and 2,99 b.y. (Allsopp et al., 1968; de Gasparis, 1967; Oosthuyzen, 1970). Similar migmatites and gneisses occur in parts of Swaziland and in areas southwest of the Barberton greenstone belt.

Forming part of the Lochiel pateau and the Transvaal and Swaziland highveld, are the homogeneous hood granites (Hunter, 1973; Viljoen and Viljoen, 1969c). The name Lochiel granite has since been proposed by Hunter (1974) for this ± 3,0 b.y. potassic granite, that has a distinctive horizontal disposition, forming a hood or carapace over the older tonalitic gneisses.

The latest granitic events in the areas surrounding the Barberton greenstone belt resulted in the intrusion of a number of medium- to coarse-grained, often porphyritic, potassic granite and syenite plutons. Two ages of pluton emplacement are recognized -- an older variety ranging between 3,1 and 2,8 b.y., and a younger variety emplaced approximately 2,6 b.y. ago (Allsopp et al., 1962; de Gasparis, 1967; Oosthuyzen, 1970). These plutons are distinctive by virtue of their topographic expression, texture, and mode of emplacement. They sharply transgress all earlier rock assemblages, including granites, and have limited effects metamorphically and structurally on formations into which they intrude (Hunter, 1973; Viljoen and Viljoen, 1969c). The Bosmanskop syenite pluton, south of the Barberton greenstone belt, falls into the older of the two age-categories. The syenite body, which consists of very coarse- to- medium- to- fine-grained syenite, syenodiorite, and granodiorite, appears to have been derived from a source depleted in Rb relative to Sr. In addition, the low initial Sr^{87}/Sr^{86} ratio, as well as low O^{18}/O^{16} values (J.R. O'Neil, personal communication, 1975), appears to rule out an older continental-crust source, and suggests that the Bosmanskop syenites were formed from partial melts of mafic magmas, possibly derived directly from the mantle (Anhaeusser, 1975b).

STRUCTURE

A number of structural investigations in various parts of the Barberton greenstone belt have contributed to a general understanding of Archean tectonic styles. Studies in selected areas of the Mountain Land led to the recognition of several periods of superimposed deformations (Anhaeusser, 1963, 1969a, 1972, 1974c; Ramsay, 1963; Roering, 1965; Urie, 1965; Viljoen, 1963). Specialized structural studies, involving the analysis of strain, were undertaken, using deformed pebbles and folds (Anhaeusser, 1969b, 1974b; Gay, 1969; Ramsay, 1963), and regional tectonic syntheses of the Mountain Land have been attempted by Anhaeusser et al. (1968) and Visser et al. (1956).

The Barberton structural studies ultimately led to the formulation of models which attempted to explain the unique, yet distinctive, deformational styles of Archean complexes (Anhaeusser et al., 1969; Anhaeusser, 1975a). Broadly, their tectonic history is seen as having developed in two stages, the first involving the gravitational slumping and downfolding of the troughs of lavas and sediments on a thin, unstable crust (Figure 4a). As the gravity-induced deformation proceeded, variably-plunging isoclinal folds formed in preferentially-developing synclinoria (Figure 4b), and steeply inclined longitudinal faults or slides were generated, the

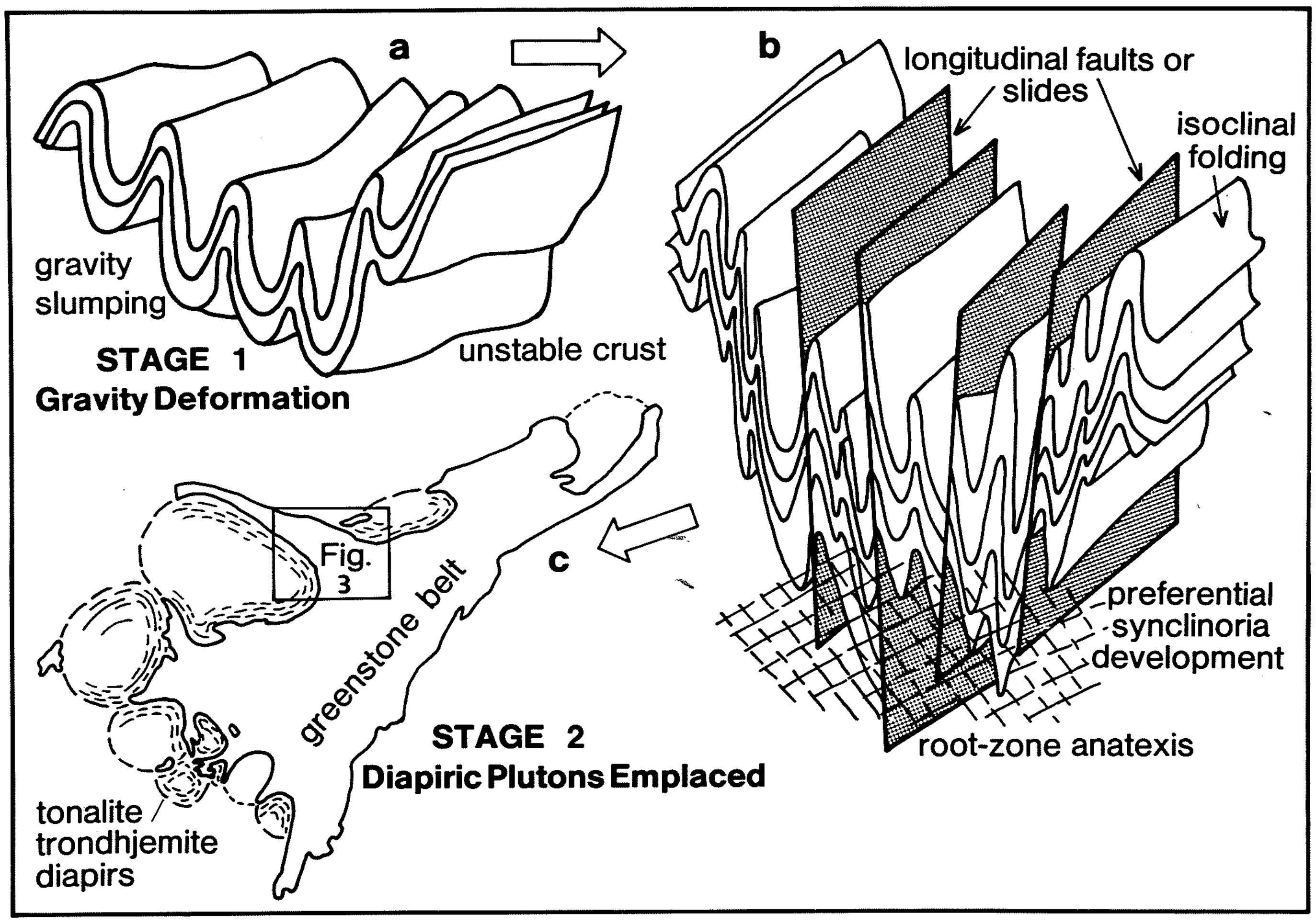


Figure 4 : *Schematic illustrations depicting episodic Archean greenstone belt deformation. Stage 1: gravity deformation on unstable crust - (a) passive slumping and warping, (b) intensified isoclinal folding, faulting, and root-zone anatexis. Stage 2: emplacement of diapiric plutons responsible for the structures shown in Figure 5. (after Anhaeusser, 1975a, with permission from Annual Review of Earth and Planetary Sciences, 3, 42. Copyright 1975 by Annual Reviews Inc.).*

latter frequently eliminating intervening anticlinal folds. Deeply infolded root-zones of the greenstone belt may have been affected by differential anatectic melting. These melts were probably responsible for the discrete diapiric tonalite/trondhjemite plutons frequently found emplaced around greenstone belt margins (Figure 4c), and, less commonly, as small stocks in the axial zones of some greenstone belts. Support for root-zone anatexis follows from the gravity studies carried out by Darracott (1975), who suggested that the deeply infolded greenstone belts had rounded or saucer-shaped keels not extending to great depths. Structures produced during the first stage were predominantly linear features, with folds possessing wavelengths and amplitudes smaller than those found in Pacific-Alpine orogenic belts (Engel and Kelm, 1972). The deformation produced by the second-stage diapiric plutonism was responsible for the intensification of greenstone belt structural complexity.

In Figure 5, structures typically resulting from granite diapirism around the margin of part of the Barberton greenstone belt are illustrated. According to Anhaeusser (1975a), the

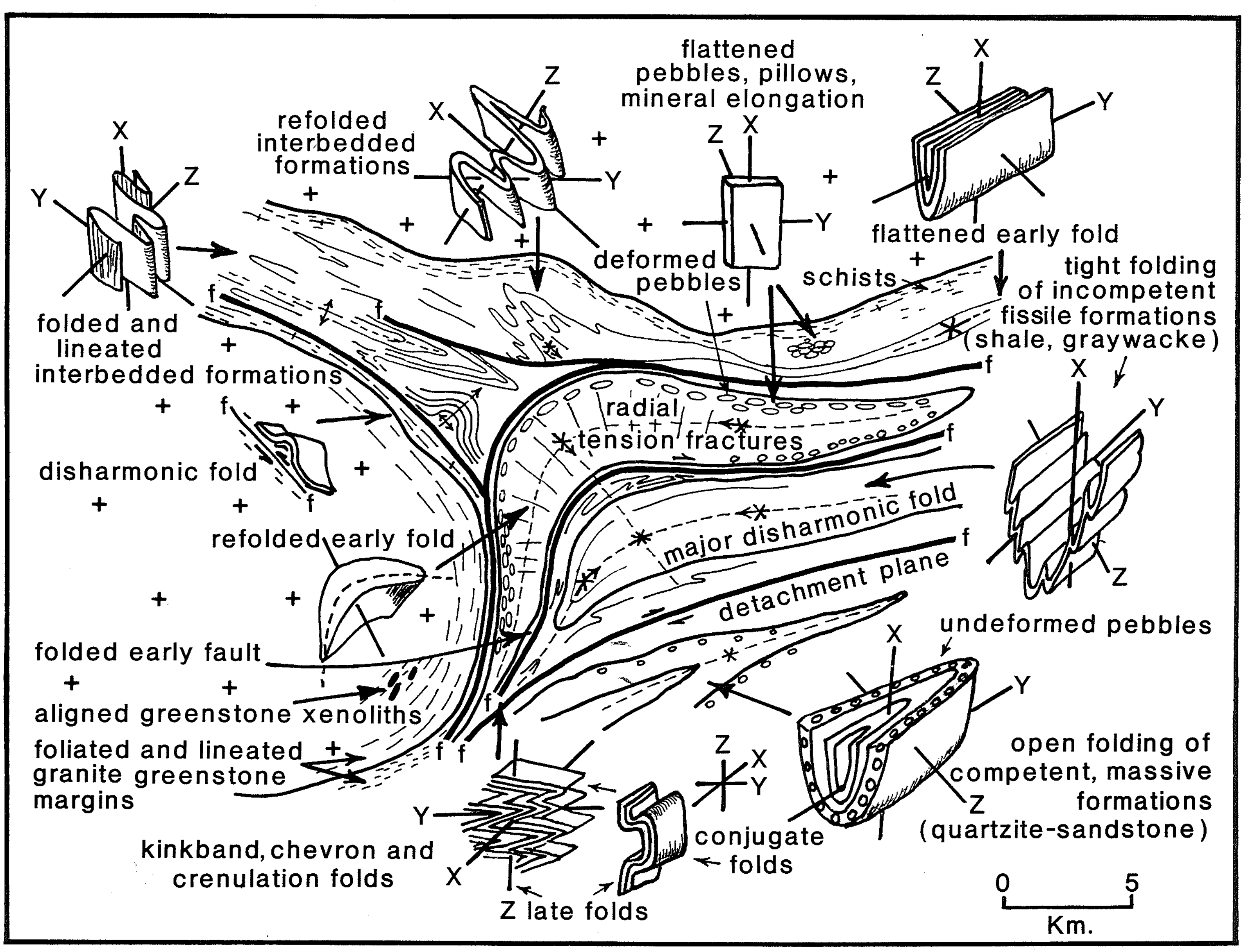


Figure 5 : *Schematic diagram illustrating the main tectonic elements and strain indicators in part of the Barberton greenstone belt deformed by the emplacement of marginal diapiric granite plutons (after Anhaeusser, 1975a, with permission from Annual Review of Earth and Planetary Sciences, 3, 43. Copyright 1975 by Annual Reviews Inc.).*

deformational events appear to have taken place in the following order : (1) the diapiric plutons prized off, stoped, and assimilated greenstone material, becoming, compositionally, more basic (hornblende-biotite tonalites) and full of inclusions, as the lavas were engulfed; (2) as the granites rose, concomitant downsagging of the adjacent greenstones occurred, and the pluton margins developed a pronounced foliation and lineation; (3) greenstone xenoliths close to granite contacts became aligned in the foliation directions of the gneisses, parallel to the greenstone belt margins, which also developed a strong schistosity parallel to the granite contacts; (4) differential compression resulted in the development of isoclinal folding, pebble and pillow flattening, and mineral re-orientation during metamorphism; (5) various fold styles developed because of competency contrasts existing between the various lithologies; (6) reactivation of earlier-formed planes of weakness produced transcurrent faults, drag and disharmonic folds, and numerous attendant second- and higher-order faults, fractures, and joints; and (7) late-stage vertical adjustments produced superimposed small- and large-scale folds (conjugate, chevron, and kink-band folds). In addition, the following three features, according to Anhaeusser (1975a), support the view that the initial deformations developed essentially under gravitational influences (as opposed to compressional tectonics accompanying crustal shortening) on a thin unstable crust: (1) very low grades of regional (dynamic) metamorphism; (2) irregular distribution, or absence, of all-pervasive, totally penetrative structures (cleavage-schistosity); and (3) preferred tendency for synclines to form and anticlines to be faulted out by high-angled slides.

GEOPHYSICAL DATA

The only effective means available at present by which reliable information can be obtained about the subsurface depth and shape of the Barberton greenstone belt is from a study of the gravity field over the region. As yet, no exhaustive geophysical studies of this type have been undertaken in the area, but attempts have been made to model regional gravity data available from Swaziland and adjacent areas of the Transvaal.

Burley et al. (1970) constructed a residual gravity map of Swaziland and a profile across the Barberton greenstone belt, based on 2 000 gravity stations in Swaziland and the gravity data available from the Transvaal. The anomalies on the residual gravity map display a distinct northeast trend, with negative and positive anomalies striking across Swaziland and coinciding with mapped limits of the Lochiel granite and the presumed retrograded granulites within the Ancient Gneiss Complex (Hunter, 1974). From their analysis, Burley et al. (1970) suggested that the gravity anomaly over the Barberton greenstone belt could be produced by an outcropping, flat, steepsided body, extending to a maximum depth of 3,2 km.

A more sophisticated approach to modelling the depth of the Barberton greenstone belt was taken by Darracott (1975), who compiled a Bouguer gravity anomaly map from 102 data points in South Africa (Smit et al., 1962) and 420 points in Swaziland (Masson-Smith and Evans, 1966). Density measurements carried out by Darracott, on rock samples from various locations in the Barberton Mountain Land, enabled representative density values to be ascribed to the three main subdivisions of the Swaziland Supergroup. Gravity profiles, an example of which is shown in Figure 6, were

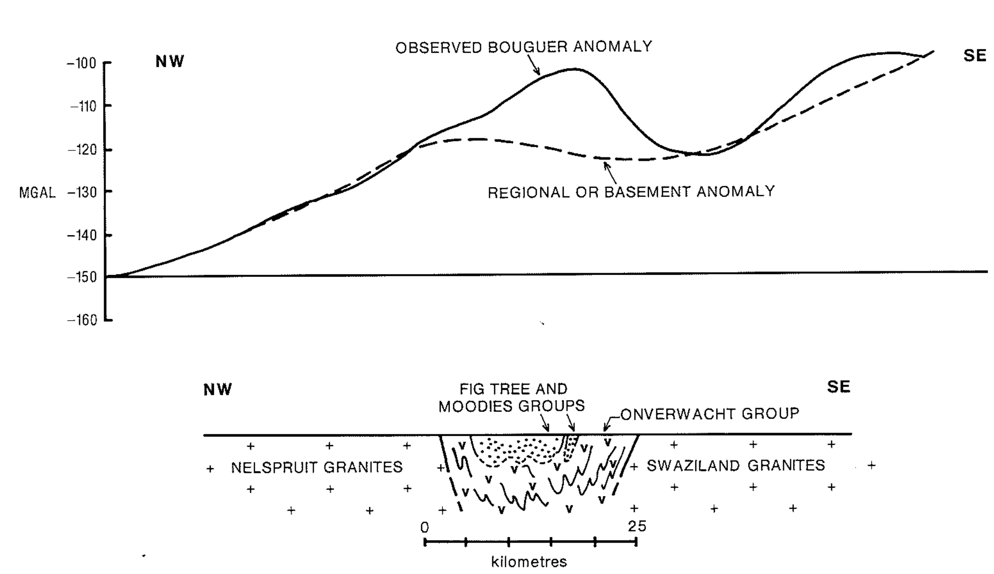


Figure 6 : Bouguer gravity anomaly profile, with schematic geological section across the Barberton greenstone belt (after Darracott, 1975).

constructed from the contour map of Bouguer anomalies, and were separated into regional and residual components. The Swaziland Supergroup rocks, it was found, are associated with a northeasterly-trending elongate, positive residual anomaly which has an amplitude of 20 to 30 milligals. The anomaly maximum lies over the outcrop of Onverwacht Group mafic and ultramafic rocks on the south-eastern side of the Mountain Land, and the anomaly profile is depressed in the northwest over the outcrop of sedimentary rocks of the Fig Tree and Moodies groups.

From the study, Darracott (1975) was able, for the first time, to differentiate quantitatively between the sedimentary and volcanic groups making up the greenstone belt. Because the refinement introduced a non-uniqueness to the interpretation, he proposed several models, and suggested that the true subsurface shape and bulk rock-type distribution at depth within the greenstone belt might be similar to the model depicted in Figure 7, which shows the situation for a uniform depth to the base of the Onverwacht volcanics. The results of the physical modelling suggest that the Barberton greenstone belt has a probable depth of 3-4 km, with the possibility of depths reaching 6 km beneath the deeply infolded sediments of the Fig Tree and Moodies groups.

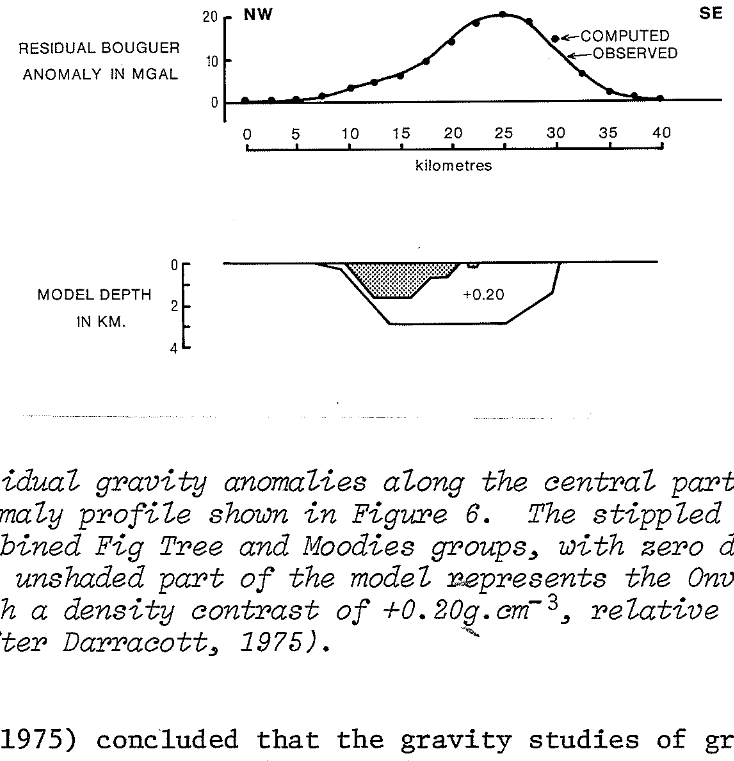


Figure 7 : *Residual gravity anomalies along the central part of the Bouguer gravity anomaly profile shown in Figure 6. The stippled area represents the combined Fig Tree and Moodies groups, with zero density contrast, and the unshaded part of the model represents the Onverwacht succession, with with a density contrast of +0.20g.cm^{-3}, relative to the basement (after Darracott, 1975).*

Darracott (1975) concluded that the gravity studies of greenstone belts have demonstrated that the Archean relics are associated with relatively positive gravity anomalies, and are essentially flat-lying, saucer-shaped bodies in relation to their areal extent. Commenting on the views of Hunter (1974), wherein it is implied that the relatively shallow depth of the Barberton schist belt relic, as deduced from gravity data, is support for a sialic crust pre-dating the Swaziland Supergroup, Darracott (1975) emphasized the fact that the gravity data can only indicate the presence of relatively low-density rocks at no great depth, and cannot positively indicate whether these rocks pre- or post-date the overlying Swaziland Supergroup.

GEOCHRONOLOGY

Isotopic age determinations carried out in the Barberton Mountain Land have confirmed that the majority of rock-types in the area exceed 3,0 b.y. in age (see Anhaeusser, 1973a, for summary of ages). The oldest ages yet reported include the Rb-Sr isochron date of 3,50 ± 0,20 b.y. for basaltic komatiite from the Tjakastad Sub-Group. This age, together with the lead ages of between 3,4-3,8 b.y. reported by Saager and Köppel (1976) exceeds those so far obtained for the Ancient Gneiss Complex (Rb-Sr isochron ages of 3,341 ± 0,5 b.y. and 3,395 ± 0,096 b.y.) (Davies, 1971). An Rb-Sr age of 3,375 ± ,02 b.y. for the Middle Marker (Hurley et al., 1972) and U-Pb ages ranging between 3,22 and 3,31 ± 0,04 b.y. for some of the diapiric plutons intruding the lower formations of the Onverwacht Group (Oosthuyzen, 1970) further confirm the great age of the primitive pile (7 km thick) of basaltic and peridotitic komatiites of the Tjakastad Sub-Group.

Zircons from quartz porphyry lavas in the Hooggenoeg Formation of the overlying Geluk Sub-Group have yielded an U-Pb age of 3,36 ± 0,10 b.y. (van Niekerk and Burger, 1969). Felsic lavas from this part of the stratigraphic column have also defined a Rb-Sr linear isochron yielding an apparent age of 2,62 ± 0,02 b.y., but this result is incompatible with previously established + 3,0 b.y. ages for granites intruding the Swaziland Supergroup (Allsopp et al., 1968, 1973). These authors interpreted the 2,6 b.y. age as the time of isotopic homogenization of the Rb-Sr system, and it was suggested that hydrothermal alteration was the probable cause of this anomalous result.

Higher in the stratigraphy, Fig Tree shales, dated by Allsopp et al. (1968), gave values of 2,98 ± 0,02 b.y. by the Rb-Sr isochron method. This reflects a minimum age only, as both the Fig Tree and Moodies sedimentary assemblages were deformed by tonalitic diapirs such as the Kaap Valley Granite pluton emplaced 3,31 ± 0,04 b.y. ago (Oosthuyzen, 1970).

As mentioned earlier, the granitic rocks of the Barberton Mountain Land have a variety of ages ranging between 3,39 and 3,22 b.y., for the early tonalitic and trondhjemitic gneisses (including those of the Ancient Gneiss Complex and the diapiric plutons), and 2,6 b.y., for some of the late potassic plutons. Between these age extremes are the Nelspruit migmatites, as well as comparable rocks south of the Mountain Land. These have yielded ages of approximately 3,16 b.y. (Allsopp et al., 1962, 1968, 1969; Davies, 1971; de Gasparis, 1967; Oosthuyzen, 1970), and are gradational into the $\sim$ 3,0 b.y.-old homogeneous potassic hood granites of the highveld plateau regions.

Finally, one of the oldest syenite plutons known from anywhere in the Archean occurs to the south of the Barberton greenstone belt. Dated at 3,13 ± 0,03 b.y. by the U-Pb method (Oosthuyzen, 1970), the Bosmanskop syenite is intruded into trondhjemitic gneisses, and, because of its low initial ratio of 0,70103 (B. Ryan, personal communication, 1975), it is considered to be mantle-derived and similar to the syenite plutons in the Archean granite-greenstone terrane of northern Minnesota (Goldich et al., 1972; Hanson and Goldich, 1972; Prince and Hanson, 1972).

PRIMITIVE LIFE

The cherts and shales of the Fig Tree Group were the first sediments to yield evidence of very primitive life-forms, dating back more than 3,0 b.y. (Barghoorn and Schopf, 1966; Pflug, 1966; Ramsay, 1963). With the reclassification of the Swartkoppie assemblage, most of the primitive micro-organisms described from the Fig Tree Group would now qualify for inclusion in the Onverwacht Group. Microstructures, considered to represent early life forms older than those in the Swartkoppie Formation, were first reported by Engel et al. (1968), who described spheroidal and cup-shaped carbonaceous alga-like bodies, as well as filamentous structures and amorphous carbonaceous matter, in black carbonaceous chert and siliceous argillites interlayered with lavas in the Theespruit and Kromberg formations. Nagy and Nagy (1969) introduced a note of caution about referring to the microstructures in the lower Onverwacht Group as microfossils, and continued using the non-genetic designation of microstructure. Permeability and porosity experiments, aimed at determining the degree of possible contamination of these rocks by organic compounds dissolved in fluids that may have flowed through the rocks for several billion years, were carried out by Nagy (1970) and Sanyal et al. (1971). Although the Onverwacht cherts have extremely low permeabilities, it was concluded that some contamination of the rocks possibly took place by means of intergranular and fracture channels.

Despite the reservations that had been expressed, Brooks et al. (1973) and Muir and Hall (1974) maintained there was ample proof of the biogenic nature of the Onverwacht micro-organisms. Two varieties of microfossil were identified, the first consisting of spheroids, and the second of filaments. Nagy and Nagy (1969) reported that the organic content of the Onverwacht rocks was mainly in the form of kerogen containing aromatic components. Brooks et al. (1973) considered this insoluble organic matter to be related to the naturally occurring polymeric material, sporopollenin, of known biogenic origin. These sporopollenins, when heated, readily yield aromatic compounds, the resulting specific mixture of which is virtually identical to that produced from most metamorphosed sedimentary kerogens. They therefore concluded that it was unnecessary to postulate a lignin precursor for the aromatic compounds in the Onverwacht sediments.

ISOTOPE GEOCHEMISTRY

A number of studies have been undertaken on rocks from the Barberton area to determine the oxygen, carbon, sulphur, lead, and strontium isotopic ratios in the oldest accessible sediments. Perry (1967) and Perry and Tan (1972) presented evidence showing how the oxygen isotopes of modern rocks differ from those in the Barberton Mountain Land.

Swaziland Supergroup	Modern Rocks
δO^{18} range (°/∘∘)	Mean δO^{18} (°/∘∘)
14,9-16,6 for siderite	33 for siderite
12,1-15,4 for dolomite	33 for dolomite
13,1-18,7 for quartz in chert	34 for Cretaceous chert
	36 for siliceous organisms

They maintained that, if the highest δO^{18} values of the ancient chert and carbonate rocks are primary, the δO^{18} of the modern ocean, which is 0 °/∘∘ today, has probably increased by about 15 °/∘∘ since their deposition. Perry and Tan (1972) pointed out further that various estimates of δO^{18} abundances in crustal rocks suggest there is a large, but poorly determined, excess of this isotope in the crust. This excess, coupled with the relatively low δO^{18} abundance established for the Archean sediments at Barberton, led to the conclusion that the ocean, 3,2 b.y. ago, was perhaps half the size of the present ocean, and that it had exchanged oxygen isotopes with crustal materials, to increase the δO^{18} of crustal rocks and simultaneously to decrease the δO^{18} of ocean water. Their observations further suggest that the recycling of water through the mantle and the addition of juvenile water have added large amounts of O^{18} to the crust.

In support of their conclusion that the stratiform barite occurrences in the Onverwacht and Fig Tree groups were derived from the upper mantle during volcanism, Perry et al. (1971) reported Sr^{87}/Sr^{86} ratios ranging from 0,70088 to 0,70172. The δS^{34} values they obtained for the barite and approximately contemporaneous sulphides from the Swaziland succession indicate small sulphur isotope variations within each group, and, unlike more recent sulphate-sulphide pairs, only a 2,5 °/∘∘ difference exists between the barite (∿ 3,4 °/∘∘) and pyrite (∿ 0,9 °/∘∘). In the modern ocean, δS^{34} of sulphate is + 20,4 °/∘∘, and stratified sulphides range between 11,7 and 17,5 °/∘∘ lower in δS^{34} than contemporary sulphates (the assumption is made that sedimentary sulphate may reasonably represent contemporary oceanic sulphate). As only supergene sulphate and sulphate from carbonaceous chondrites have low δS^{34} values comparable with the Barberton barite, Perry et al. (1971) suggested that their data show that the Archean sulphur cycle was grossly different to that of the present. They concluded that the sulphur isotopic evidence also supports the view that the atmosphere was less oxidizing in the early Precambrian than at present (Cloud, 1968; Holland, 1962).

Data from the ancient carbonate rocks in the Barberton area and elsewhere indicate that a change in atmospheric oxygen pressure through time has not been accompanied by corresponding changes in δC^{13}. Studies by Nagy et al. (1974), Perry and Tan (1972), and Schidlowski et al. (1975), have shown that the carbonate δC^{13} abundances do not vary significantly from the range of carbon isotope ratios recorded in modern marine carbonates. This implies further that the δC^{13} content of marine carbonate is not a satisfactory indicator of the oxygen content of the atmosphere (Perry and Tan, 1972). Oehler et al. (1972) reported anomalously heavy reduced carbon in cherts from the Theespruit Formation (average δC^{13} = 16,5 °/∘∘), compared with δC^{13} = -28,7 °/∘∘ for middle and upper Onverwacht and Fig Tree cherts. It was speculated that the discontinuity might reflect a major event in evolution, but McKirdy and Powell (1974) showed subsequently that diagenesis and metamorphic rank (the latter given by the H/C atomic ratios) are responsible for δC^{13} isotopic variations in the metamorphosed Theespruit sediments.

Strontium isotopic ratios are available for a variety of rock-types in the Barberton Mountain Land, and complement the geochronological studies. Space does not permit more than a brief mention of the low initial Sr^{87}/Sr^{86} ratios reported for some of the primitive volcanic rocks of the Onverwacht Group. Initial Sr^{87}/Sr^{86} ratios ($R_\circ$) were calculated by Allsopp et al. (1973) for nine basic and ultrabasic rocks, mainly from the Hooggenoeg and Kromberg formations, with one sample of anorthosite from the Koedoe layered ultramafic complex and one from the Komati Formation. Five samples yielded R_o = 0,7002, two gave R_o = 0,7029, and two gave R_o = 0,7058 (precision ± 0,0003). Confirmatory data (Jahn and Shih, 1974), from five mineral separates and one whole-rock analysis of basaltic komatiite from the Komati Formation, defined an isochron of t = 3,50 ± 0,20 (2 σ) b.y., with a corresponding initial Sr^{87}/Sr^{86} ratio of 0,70048 ± 5 (2 σ). The low initial Sr^{87}/Sr^{86} ratios are important to an understanding of the Sr-isotopic composition of the Archean upper mantle. The R_o values of $\sim$ 0,700 conform to a model of linear Sr-isotope evolution in those regions of the mantle from which abyssal tholeiites are derived. The low R_o values also lend support to the identification or comparison of the Barberton komatiites with abyssal oceanic volcanics. They further define an upper limit for the Sr-isotopic composition of the Archean upper mantle beneath the crust in the Barberton region, and place constraints on any model of Sr isotopic evolution in the upper mantle (Jahn and Shih, 1974).

Finally, lead isotopic investigations of sulphides from gold-sulphide deposits in the Barberton Mountain Land have indicated that the primary lead of the sulphides is a two-stage lead forming a secondary isochron (Saager and Köppel, 1976; Ulrych et al., 1967). The lead isotope ratios presented by Ulrych et al. (1967) were, until recently, the least radiogenic ratios thus far determined for terrestrial leads, and yielded a model age of 3,46 b.y. for galena and other Pb sulphides. Saager and Köppel (1976) have since reported new least radiogenic lead isotopic ratios from galena samples from the Old Star Mine in the Murchison Range, 200 km north of Barberton ($^{206}Pb/^{204}Pb$ = 12,198; $^{207}Pb/^{204}Pb$ = 13,819; $^{208}Pb/^{204}Pb$ = 32,06). Using the minimum age for the mineralization of 3,03 b.y., as indicated by Rb-Sr data from pegmatites cutting the ore at the Consort Mine (Allsopp et al., 1968), Saager and Köppel (1976) found that the $^{207}Pb/^{206}Pb$ ratio of the secondary isochron (0,8065 ± 0,009) pointed to a minimum age of 3,45 b.y. and a maximum age of 3,80 b.y. for the Onverwacht Group rocks.

THE SIGNIFICANCE OF THE BARBERTON MOUNTAIN LAND IN EARTH HISTORY

Advances in radiometric dating techniques have, in recent years, contributed greated to an intensification of the search for the oldest terrestrial rocks. Very ancient ages, ranging between 3,5 and 3,8 b.y., are now known from the Godthaab and Isua regions of West Greenland (Moorbath et al., 1972, 1973), the Minnesota River Valley (Goldich, 1972), the Mashaba area of the Rhodesian craton (Hawkesworth et al., 1975; Hickman, 1974), and from the Vredefort granite dome in South Africa (H. Welke, personal communication, 1975). Except for the Isua area, where basic rocks containing banded iron-formation (oxide- and carbonate-facies) are enclosed in gneisses $\sim$ 3,7 b.y. old (Moorbath et al., 1973), all the ancient rocks so far discovered consist of complex migmatite-gneiss terranes. The Archean greenstone belts of Southern Africa, and particularly the Barberton greenstone belt, therefore, represent the earliest clearly decipherable geological events on the Earth's surface, and any clues concerning the nature and evolutionary development of the primitive atmosphere, hydrosphere, lithosphere, and biosphere must be sought largely from an examination of their lithologies.

Among the basal stratigraphic units of the Swaziland Supergroup are remnants of what might once have been part of a primitive ensimatic crust, predating the various granites and gneisses now enveloping the region. How old these primitive basalts and peridotites might be still remains to be determined. Indications are that they could range back in time to between 3,5 and 3,8 b.y.

Gravitational instability and crustal foundering of vast areas of primordial ensimatic lithosphere are seen as possible mechanisms initiating partial melting and calc-alkaline volcanism and plutonism which led to anorogenic sialic crustal growth in post-Middle Marker times in the Barberton model. Although it is doubtful whether plate tectonics, as understood today, operated in the Archean (Anhaeusser, 1975a), it is tempting to call upon processes akin to those responsible for modern island-arc development to help explain upper Onverwacht-type volcanism in greenstone belts. However, the absence of blueschists and paired metamorphism, so common in Phanerozoic orogenic belts and in circum-Pacific island arcs (Anhaeusser, 1975a; Engel, 1970), introduces a few of the difficulties encountered if direct equivalence is to be sought between the ancient and modern situations.

The sedimentary successions in the Barberton greenstone belt indicate two contrasting depositional regimes. The Fig Tree assemblage displays evidence of having been deposited in relatively deep water, associated with turbidity flows, whereas Moodies sedimentation appears continental in character and similar to sediments formed later in Proterozoic interior or cratonic basins (e.g. Pongola, Witwatersrand, or Transvaal basins). The disparity of lithological and depositional styles between the sedimentary groups further supports the view that the ensialic crustal component was undergoing continued modification throughout the later history of the Barberton region. Although most of the early granites and gneisses were tonalitic, it is evident, from studies of granite boulders in Moodies conglomerates, that potassium-rich varieties must have occurred in the provenance areas (Anhaeusser, 1966, 1969a, 1973a; Krupicka, 1975). The K-rich granites would have been the first to be eroded, if they had occupied topographically elevated regions of the granite terranes, as they do today in parts of Swaziland and in areas north and south of Barberton (Hunter, 1973; Viljoen and Viljoen, 1969c).

The cratonic nature of Moodies sedimentation and the deep infolding of the successions suggest a transition from geosynclinal to cratonic conditions about 3,3 b.y. ago in the Barberton region. This transition was undoubtedly influenced by crustal thickening, brought about possibly by granite underplating (Engel, 1970). Final stabilization in the area was attained approximately 3,0 b.y. ago, when the first interior-basin sediments of the Pongola Supergroup were laid down (Anhaeusser, 1973a).

Structural investigations in the Barberton Mountain Land, coupled with clarity of the relations of the greenstone belt to the granitic rocks in the area, have contributed to the formulation of Archean tectonic models. It is visualized that, following initial gravity-induced deformations, the Barberton greenstone belt suffered superimposed metamorphism and tectonism, the latter caused mainly by marginal-granite diapirism.

In addition to the observations which assist in understanding aspects of lithospheric evolution, the Barberton rocks, and others like them elsewhere, have placed limitations on conjecture about the nature of the primitive atmosphere, hydrosphere, and biosphere. It is certain, from the great developments of pillow structures and quench phenomena in Archean lavas, that the volcanics were deposited in bodies of water or primordial seas, which, according to oxygen isotope studies, were very much smaller than modern oceans. In addition, sulphur isotope data from chemical sediments in greenstone belts, as well as converging lines of evidence from elsewhere in Southern Africa (detrital uraninite and pyrite), make it apparent that the early atmosphere contained little or no free oxygen. Furthermore, as Cloud (1968) has indicated, the abundance of chert in the Archean and the relative rarity of carbonates imply also that there could have been little ammonia in the atmosphere of these times, as ammonia would have raised the pH of the hydrosphere, thereby producing an abundance of carbonates and a rarity of cherts. A methane-rich atmosphere is also discredited, as greater abundances of carbon would have been produced than are found. The volcanic environments, displayed in the Archean, were far more likely to have contributed H_2O, CO_2, N_2, SO_2, CO, and HCl to the early atmosphere.

Finally, the earliest life-forms known on earth first appeared in the Barberton sediments. Initially, life was presumably anaerobic, but gradually oxygen-releasing photosynthesizing micro-biota evolved which may have depended upon ferrous iron to maintain ambient oxygen at tolerable levels, before expanding and diversifying, converting the iron to insoluble ferric oxides (Cloud, 1968, 1972). The oxygen, according to Cloud's model, became locked in the chemical sediments, particularly the banded iron-formations, until the hydrosphere was rid of all its ferrous cations approximately 2,0 b.y. ago. Thereafter, O_2 accumulated rapidly and began to enter the atmosphere.

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REFERENCES

Allsopp, H.L., Roberts, H.R., Schreiner, G.D.L., and Hunter, D.R. (1962). Rb-Sr age measurements on various Swaziland granites. J. Geophys. Res., 67, 5307-5313.

Allsopp, H.L., Ulrych, J.J., and Nicolaysen, L.O. (1968). Dating some significant events in the history of the Swaziland System by the Rb-Sr method. Can. J. Earth Sci., 5, 605-619.

Allsopp, H.L., Davies, R.D., De Gasparis, A.A.A., and Nicolaysen, L.O. (1969). Review of Rb-Sr age measurements from the early Precambrian terrain in the south-eastern Transvaal and Swaziland. Spec. Publ. 2, Geol. Soc. S. Afr., 433-443.

Allsopp, H.L., Viljoen, M.J., and Viljoen, R.P. (1973). Strontium isotopic studies of the mafic and felsic rocks of the Onverwacht Group of the Swaziland Sequence. Geol. Rundschau, 62, 902-917.

Anhaeusser, C.R. (1963). The geology of the Lily Syncline and portion of the Eureka Syncline between Sheba Siding and Louw's Creek Station, Barberton Mountain Land. Unpub. M.Sc. Thesis, Univ. Witwatersrand, Johannesburg.

Anhaeusser, C.R. (1966). Facets of the granitic assemblage on the northwest flank of the Barberton Mountain Land. Inform Circ. 32, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 27 pp.

Anhaeusser, C.R. (1969a). The stratigraphy, structure, and gold mineralization of the Jamestown and Sheba Hills areas of the Barberton Mountain Land. Unpub. Ph.D. Thesis, Univ. Witwatersrand, Johannesburg.

Anhaeusser, C.R. (1969b). A comparison of pebble and fold deformations in the Nelspruit granite contact aureole, Barberton Mountain Land. Trans., Geol. Soc. S. Afr., 72, 49-60.

Anhaeusser, C.R. (1971a). The Barberton Mountain Land, South Africa - a guide to the understanding of the Archaean geology of Western Australia. Spec. Publ. 3, Geol. Soc. Australia, 103-119.

Anhaeusser, C.R. (1971b). Cyclic volcanicity and sedimentation in the evolutionary development of Archaean greenstone belts of shield areas. Spec. Publ. 3, Geol. Soc. Australia, 57-70.

Anhaeusser, C.R. (1972). The geology of the Jamestown Hills area of the Barberton Mountain Land, South Africa. Trans., Geol. Soc. S. Afr., 75, 225-263.

Anhaeusser, C.R. (1973a). The evolution of the early Precambrian crust of Southern Africa. Phil. Trans., R. Soc. Lond., A.273, 359-388.

Anhaeusser, C.R. (1973b). The Stolzburg differentiated ultramafic igneous complex, Barberton Mountain Land. Abstr., 15th Congr., Geol. Soc. S. Afr., Bloemfontein, 69-72.

Anhaeusser, C.R. (1974a). Archean metallogeny in Southern Africa. Inform. Circ. 91, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 38 pp.

Anhaeusser, C.R. (1974b). The nature of chrysotile asbestos occurrences in Southern Africa - a review. Inform. Circ. 90, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 28 pp.

Anhaeusser, C.R. (1974c). The geology of the Sheba Hills area of the Barberton Mountain Land, South Africa, with particular reference to the Eureka Syncline. Inform. Circ. 94, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 47 pp.

Anhaeusser, C.R. (1975a). Precambrian tectonic environments. Ann. Rev. Earth Planet. Sci., 3, 31-53.

Anhaeusser, C.R. (1975b). The Archaean granite-greenstone terrane in the vicinity of the Bosmanskop syenite pluton, Barberton Mountain Land. Abstr., 16th Congr., Geol. Soc. S. Afr., Stellenbosch, 5-7.

Anhaeusser, C.R., Mason, R., Viljoen, M.J., and Viljoen, R.P. (1969). A reappraisal of some aspects of Precambrian shield geology. Bull., Geol. Soc. Amer., 80, 2175-2200.

Anhaeusser, C.R., Roering, C., Viljoen, M.J., and Viljoen, R.P. (1968). The Barberton Mountain Land : a model of the elements and evolution of an Archaean fold belt. Annex. Trans., Geol. Soc. S. Afr., 71, 225-253.

Anhaeusser, C.R., and Viljoen, M.J. (1965). The base of the Swaziland System in the Barberton-Noordkaap-Louw's Creek area, Barberton Mountain Land. Inform. Circ. 25, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 32 pp.

Barghoorn, E.S., and Schopf, J.W. (1966). Micro-organisms three billion years old from the Precambrian of South Africa. Science, 152, 758-763.

Beukes, N.J. (1973). Precambrian iron-formations of Southern Africa. Econ. Geol., 68, 960-1004.

Brooks, C., and Hart, S. (1972). An extrusive basaltic komatiite from a Canadian Archean meta-volcanic belt. Can. J. Earth Sci., 9, 1250-1253.

Brooks, C., and Hart, S. (1974). On the significance of komatiite. Geology, 2, 107-110.

Brooks, J., Muir, M.D., and Shaw, G. (1973). Chemistry and morphology of Precambrian micro-organisms. Nature, 244(5413), 215-217.

Burley, A.J., Evans, R.B., Gillingham, J.M., and Masson-Smith, D. (1970). Gravity anomalies in Swaziland. Bull. 7, Geol. Surv. Swaziland, 4-16.

Bursill, C., Luyt, J.R.M., and Urie, J.G. (1964). The Bomvu Ridge iron ore deposits. in The Geology of Some Ore Deposits in Southern Africa (S.H. Haughton, ed.), Geol. Soc. S. Afr., 2, 405-414.

Cawthorn, R.G., and Strong, D.F. (1974). The petrogenesis of komatiites and related rocks as evidence for a layered upper mantle. Earth Planet. Sci. Lett., 23, 369-375.

Cloud, P. (1968). Atmospheric and hydrospheric evolution on the primitive earth. Science, 160, 729-736.

Cloud, P. (1972). A working model of the primitive earth. Amer. J. Sci., 272, 138-149.

Condie, K.C., Macke, J.E., and Reimer, T.O. (1970). Petrology and geochemistry of early Precambrian greywackes from the Fig Tree Group, South Africa. Bull., Geol. Soc. Amer., 81, 2759-2776.

Darracott, B.W. (1975). The interpretation of the gravity anomaly over the Barberton Mountain Land, South Africa. Trans., Geol. Soc. S. Afr., 78, (in press).

Davies, R.D. (1971). Geochronology and isotopic evolution of the early Precambrian crustal rocks in Swaziland. Unpub. Ph.D. Thesis, Univ. Witwatersrand, Johannesburg.

De Gasparis, A.A. (1967). Rb-Sr isotopic studies relating to problems of geochronology on the Nelspruit and Mpageni granites. Unpub. M.Sc. Thesis, Univ. Witwatersrand, Johannesburg.

Engel, A.E.J. (1970). The Barberton Mountain Land : clues to the differentiation of the earth. in Adventures in Earth History (P. Cloud, ed.), W.H. Freeman and Co., San Francisco, 431-445.

Engel, A.E.J., and Kelm, D.L. (1972). Pre-Permian global tectonics : a tectonic test. Bull., Geol. Soc. Amer., 83, 2325-2340.

Engel, A.E.J., Nagy, B., Nagy, L.A., Engel, C.G., Kremp, G.O.W., and Drew, C.M. (1968). Alga-like forms in Onverwacht Series, South Africa : oldest recognized lifelike forms on earth. Science, 161, 1005-1008.

Fyfe, W.S. (1973). The granulite facies, partial melting and the Archaean crust. Phil. Trans., R. Soc. Lond., A.273, 457-461.

Gay, N.C. (1969). The analysis of strain in the Barberton Mountain Land, eastern Transvaal, using deformed pebbles. J. Geol., 77, 377-396.

Goldich, S.A., Hanson, G.N., Hallford, C.R., and Mudrey, M.G. (1972). Early Precambrian rocks in the Saganaga Lake - Northern Light Lake area, Minnesota - Ontario. Mem. 135, Geol. Soc. Amer., 151-177.

Goldich, S.S. (1972). Geochronology in Minnesota. in Geology of Minnesota : a Centennial Volume (P.K. Sims and G.B. Morey, eds.), Geol. Surv. Minnesota, 27-37.

Green, D.H. (1972a). Magmatic activity as the major process in the chemical evolution of the earth's crust and mantle. Tectonophysics, 13, 47-71.

Green D.H. (1972b). Archaean greenstone belts may include terrestrial equivalents of lunar maria? Earth Planet. Sci. Lett., 15, 263-270.

Green, D.H. (1975). Genesis of Archean peridotitic magmas and constraints on Archean geothermal gradients and tectonics. Geology, 3, 15-18.

Green, D.H., Nicholls, I.A., Viljoen, M.J., and Viljoen, R.P. (1975). Experimental demonstration of the existence of peridotitic liquids in earliest Archean magmatism. Geology, 3, 11-14.

Hall, A.L. (1918). The geology of the Barberton gold mining district. Mem. 9, Geol. Surv. S. Afr., 347 pp.

Hanson, G.N., and Goldich, S.S. (1972). Early Precambrian rocks in the Saganaga Lake - Northern Light Lake area, Minnesota - Ontario. Mem. 135, Geol. Soc. Amer., 171-192.

Hart, S.R., Brooks, C., Krogh, T.E., Davis, G.L., and Nava, D. (1970). Ancient and modern volcanic rocks : a trace element model. Earth Planet. Sci. Lett., 10, 17-29.

Hawkesworth, C.J., Moorbath, S., O'Nions, R.K., and Wilson, J.F. (1975). Age relationships between greenstone belts and "granites" in the Rhodesian Archaean craton. Earth Planet. Sci. Lett., 25, 251-262.

Hickman, M.H. (1974). 3,500-m.y.-old granite in southern Africa. Nature, 251(5473), 295-296.

Holland, H.D. (1962). Model for the evolution of the earth's atmosphere. in Petrologic Studies - a Volume in Honor of A.F. Buddington (A.E.J. Engel, H.L. James, and B.F. Leonard, eds.), Geol. Soc. America, 447-477.

Hunter, D.R. (1957). The geology, petrology and classification of the Swaziland granites and gneisses. Trans., Geol. Soc. S. Afr., 60, 85-125.

Hunter, D.R. (compiler) (1961). The geology of Swaziland. Geol. Surv. Swaziland, 104 pp.

Hunter, D.R. (1970). The Ancient Gneiss Complex in Swaziland. Trans., Geol. Soc. S. Afr., 73, 107-150.

Hunter, D.R. (1973). The granitic rocks of the Precambrian in Swaziland. Spec. Publ. 3, Geol. Soc. S. Afr., 131-145.

Hunter, D.R. (1974). Crustal development in the Kaapvaal craton, I. the Archaean. Precambrian Res., 1, 259-294.

Hurley, P.M., Pinson, W.H., Nagy, B., and Teska, T.M. (1972). Ancient age of the Middle Marker horizon, Onverwacht Group, Swaziland Sequence, South Africa. Earth Planet. Sci. Lett., 14, 360-366.

Jahn, B.M., and Shih, C.Y. (1974). On the age of the Onverwacht Group, Swaziland Sequence, South Africa. Geochim. Cosmochim. Acta., 38, 873-885.

Jamieson, B.G., and Clarke, D.B. (1970). Potassium and associated elements in tholeiitic basalts. J. Petrol., 11, 183-204.

Krupicka, J. (1975). Early Precambrian rocks of granitic composition. Can. J. Earth. Sci., 12, 1307-1315.

Laubscher, D.H. (1968). The origin and occurrence of chrysotile asbestos in the Shabani and Mashaba areas, Rhodesia. Annex. Trans., Geol. Soc. S. Afr., 71, 195-204.

Masson-Smith, D., and Evans, R.B. (1966). Gravity survey of Swaziland. Geophys. Rep. 33, Inst. Geol. Sciences, London, (unpubl.)

McIver, J.R., and Lenthall, D.H. (1974). Mafic and ultramafic extrusives of the Barberton Mountain Land in terms of the CMAS system. Precambrian Res., 1, 327-343.

McKirdy, D.M., and Powell, T.G. (1974). Metamorphic alteration of carbon isotopic composition in ancient sedimentary organic matter : new evidence from Australia and South Africa. Geology, 2, 591-595.

Moorbath, S., O'Nions, R.K., Pankhurst, R.J., Gale, N.H., and McGregor, V.R. (1972). Further rubidium-strontium age determinations on the very early Precambrian rocks of the Godthaab district, West Greenland. Nature, 240, 78.

Moorbath, S., O'Nions, R.K., and Pankhurst, R.J. (1973). Early Archaean age for the Isua iron formation, West Greenland. Nature, 245, 138-139.

Muir, M.D., and Hall, D.O. (1974). Diverse microfossils in Precambrian Onverwacht Group rocks of South Africa. Nature, 252, 376-378.

Nagy, B. (1970). Porosity and permeability of the early Precambrian Onverwacht chert : origin of the hydrocarbon content. Geochim. Cosmochim. Acta, 34, 525-527.

Nagy, B., and Nagy, L.A. (1969). Early Precambrian Onverwacht microstructures : possibly the oldest fossils on earth? Nature, 223(5212), 1226-1229.

Nagy, B., Kunen, S.M., Zumberge, J.E., Long, A., Moore, C., Lewis, C.F., Anhaeusser, C.R., and Pretorius, D.A. (1974). Carbon content and carbonate ^{13}C abundances in the early Precambrian Swaziland sediments of South Africa. Precambrian Res., 1, 43-48.

Naqvi, S.M. (1971). The petrochemistry and significance of Jogimardi traps, Chitaldrug Schist belt, Mysore. Bull. Volcanol., 35, 1069-1093.

Nesbitt, R.W. (1971). Skeletal crystal forms in the ultramafic rocks of the Yilgarn Block, Western Australia : evidence for an Archaean ultramafic liquid. Spec. Publ. 3, Geol. Soc. Australia, 331-347.

Oehler, D.Z., Schopf, J.W., and Kvenvolden, K.A. (1972). Carbon isotopic studies of organic matter in Precambrian rocks. Science, 175, 1246-1248.

O'Hara, M.J. (1968). The bearing of phase equilibria studies in synthetic and natural systems on the origin and evolution of basic and ultrabasic rocks. Earth-Sci. Rev., 4, 69-133.

Oosthuyzen, E.J. (1970). The geochronology of a suite of rocks from the granitic terrain surrounding the Barberton Mountain Land. Unpub. Ph.D. Thesis, Univ. Witwatersrand, Johannesburg.

Perry, E.C. (1967). The oxygen isotope chemistry of ancient cherts. Earth Planet. Sci. Lett., 3, 62-66.

Perry, E.C., Monster, J., and Reimer, T.O. (1971). Sulphur isotopes in Swaziland System barites and the evolution of the earth's atmosphere. Science, 171, 1015-1016.

Perry, E.C., and Tan, F.C. (1972). Significance of oxygen and carbon isotope variations in early Precambrian cherts and carbonate rocks of Southern Africa. Bull., Geol. Soc. Amer., 83, 647-664.

Pflug, H.D. (1966). Structured organic remains from the Fig Tree Series of the Barberton district, eastern Transvaal. Inform. Circ. 28, Econ. Geol. Res. Unit, Univ. Witwatersrand, 14 pp.

Prince, L.A., and Hanson, G.N. (1972). Rb-Sr isochron ages for the Giants Range Granite, north-eastern Minnesota. Mem. 135, Geol. Soc. Amer., 217-224.

Pyke, D.R., Naldrett, A.J., and Eckstrand, O.R. (1973). Archean ultramafic flows in Munro Township, Ontario. Bull., Geol. Soc. Amer., 84, 955-978.

Ramsay, J.G. (1963). Structural investigations in the Barberton Mountain Land, eastern Transvaal. Trans., Geol. Soc. S. Afr., 66, 353-398.

Reimer, T.O. (1967). Die Stolzburg Synklinale, Beitrag zur Geologie des Barberton Berglandes (Transvaal-Süd Afrika). Diplomarbeit Geolog.-Palaeont., Institut der Johann Wolfgang Goethe Universität, Frankfurt.

Reimer, T.O. (1973). Untersuchungen über Abtragung, Sedimentation und Diagenese in Frühen Präkambrium am Beispiel der Sheba-Formation (Süd Afrika). Unpub. Ph.D. Thesis, Goethe Univ., Frankfurt.

Reimer, T.O., and Heinrich, T. (1975). A sedimentary barite deposit from the early Precambrian Fig Tree Group. Sedimentology, (in press).

Roering, C. (1965). The tectonics of the main gold-producing area of the Barberton Mountain Land. Inform. Circ. 23, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 23 pp.

Roering, C. (1967). Non-orogenic granites in the Archaean geosyncline of the Barberton Mountain Land. Inform. Circ. 35, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 13 pp.

Saager, R., and Köppel, V. (1976). Lead isotopes and trace elements from sulfides of Archean greenstone belts in South Africa - a contribution to the knowledge of the oldest known mineralization. Econ. Geol., 71, (in press).

Sanyal, S.K., Kvenvolden, K.A., and Marsden, S.S. (1971). Permeabilities of Precambrian Onverwacht cherts and other low permeability rocks. Nature, 232(5309), 325-327.

Schidlowski, M., Eichmann, R., and Junge, C.E. (1975). Precambrian sedimentary carbonates : carbon and oxygen isotope geochemistry and implications for the terrestrial oxygen budget. Precambrian Res., 2, 1-69.

Smit, P.J., Hales, A.L., and Gough, D.J. (1962). The gravity survey of the Republic of South Africa. Handb. 3, Geol. Surv. S. Afr., 371 pp.

Stowe, C.W. (1968a). Intersecting fold trends in the Rhodesian basement south and east of Selukwe. Annex. Trans., Geol. Soc. S. Afr., 71, 53-78.

Stowe, C.W. (1968b). The geology of the country south and west of Selukwe. Bull. 59, Geol. Surv. Rhod., 209 pp.

Urie, J.G. (1965). A reconnaissance structural investigation in the Forbes Reef area, Swaziland. 8th Ann. Congr., Geol. Soc. S. Afr., Johannesburg, (unpubl.)

Ulrych, T.J., Burger, A.J., and Nicolaysen, L.O. (1967). Least radiogenic terrestrial leads. Earth Planet. Sci. Lett., 2, 179-184.

Van Niekerk, C.G., and Burger, A.J. (1969). A note on the minimum age of the acid lava of the Onverwacht Series of the Swaziland System. Trans., Geol. Soc. S. Afr., 72, 9-21.

Van Vuuren, C.J.J. (1964). The geology of portion of the Ulundi Syncline between Hislop's Creek and Fig Tree Creek, Barberton Mountain Land. Unpub. Rep., Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 133 pp.

Viljoen, M.J. (1963). The geology of the Lily Syncline and portion of the Eureka Syncline between the Consort Mine and Joe's Luck Siding, Barberton Mountain Land. Unpub. M.Sc. Thesis, Univ. Witwatersrand, Johannesburg.

Viljoen, M.J., and Viljoen, R.P. (1969a). The geology and geochemistry of the Lower Ultramafic Unit of the Onverwacht Group and a proposed new class of igneous rocks. Spec. Publ. 2, Geol. Soc. S. Afr., 55-85.

Viljoen, R.P., and Viljoen, M.J. (1969b). The geological and geochemical significance of the upper formations of the Onverwacht Group. Spec. Publ. 2, Geol. Soc. S. Afr., 113-151.

Viljoen, M.J., and Viljoen, R.P. (1969c). A proposed new classification of the granitic rocks of the Barberton region. Spec. Publ. 2, Geol. Soc. S. Afr., 153-180.

Viljoen, M.J., and Viljoen, R.P. (1969d). The geochemical evolution of the granitic rocks of the Barberton region. Spec. Publ. 2, Geol. Soc. S. Afr., 189-218.

Viljoen, R.P., and Viljoen, M.J. (1969e). The relationship between mafic and ultramafic magma derived from the upper mantle and the ore deposits of the Barberton region. Spec. Publ. 2, Geol. Soc. S. Afr., 221-244.

Viljoen, M.J., and Viljoen, R.P. (1970a). Archaean vulcanicity and continental evolution in the Barberton region, Transvaal. in African Magmatism and Tectonics (T.N. Clifford and I. Gass, eds.), Oliver and Boyd, Edinburgh, 27-39.

Viljoen, R.P., and Viljoen, M.J. (1970b). The geology and geochemistry of the layered ultramafic bodies of the Kaapmuiden area, Barberton Mountain Land. Spec. Publ. 1, Geol. Soc. S. Afr., 661-688.

Viljoen, R.P., and Viljoen, M.J. (1971). The geological and geochemical evolution of the Onverwacht volcanic group of the Barberton Mountain Land, South Africa. Spec. Publ. 3, Geol. Soc. Australia, 133-149.

Visser, D.J.L. (compiler) (1956). The geology of the Barberton area. Spec. Publ. 15, Geol. Surv. S. Afr., 253 pp.

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