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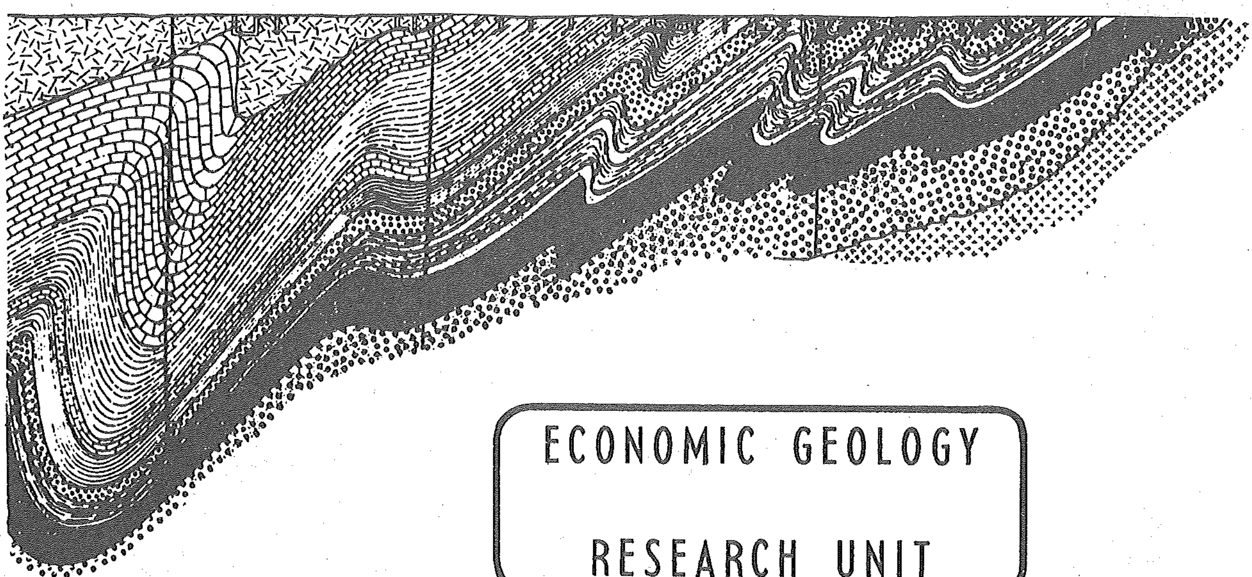

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THE BARBERTON MOUNTAIN LAND : A MODEL OF THE ELEMENTS AND EVOLUTION OF AN ARCHEAN FOLD BELT

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THE BARBERTON MOUNTAIN LAND : A MODEL OF THE ELEMENTS AND EVOLUTION OF AN ARCHEAN FOLD BELT

ABSTRACT

The Barberton Mountain Land forms one of the best developed and best preserved remnants of Archean strata in South Africa. The volcanics and sediments are similar to those associated with geosynclines and island arcs. The Onverwacht Series of the Swaziland System, consists mainly of basaltic and ultrabasic rocks together with siliceous sediments and constitutes the initial magmatic or ophiolite assemblage of the Swaziland geosyncline. The Fig Tree Series, composed primarily of greywackes, shales, banded cherts and banded ironstones displays characteristics of a flysch assemblage of rocks while finally, the overlying Moodies Series, made up of conglomerates, quartzites, shales and jaspilites, displays the characteristics of a molasse assemblage of a geosyncline.

The entire area is surrounded and swamped by granites and gneisses, thereby making it impossible to identify the miogeosynclinal and the cratonic areas associated with the Barberton Mountain Land remnant. Furthermore, the granites are not typical of normal geosynclinal areas and constitute an anomalous event, probably much later than the orogenic episode.

Evidence is presented that the Onverwacht and Fig Tree Series of rocks were deposited in a deep trough (pillow lavas, turbidites). A brief account of the structural history of the area is given and some notes on the mineralization are included. A model is suggested for the major evolutionary events in the development of the Barberton Mountain Land. The first event was the geosynclinal cycle, while the granites make up the second event. It is suggested that the Barberton Mountain Land represents a fold belt in which the geosynclinal and granite cycles are well-displayed, and, as a result, may assist in a better understanding of the evolution and development of other, less well-developed schist belt remnants in Archean granite terrains of continental shield areas.

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THE BARBERTON MOUNTAIN LAND : A MODEL OF THE ELEMENTS AND EVOLUTION OF AN ARCHEAN FOLD BELT

INTRODUCTION

With the aim of discovering further sources of mineable ore the Barberton Mountain Land has been subjected to intensive geological investigations over the last six years. This work, undertaken by the Economic Geology Research Unit of the University of the Witwatersrand, in conjunction with various mining companies and the Swaziland Geological Survey, has given rise to a wealth of basic data. In addition, the area is at present being examined as part of South Africa's contribution to the International Upper Mantle Project. This work is primarily concerned with a study of the various ancient lavas and ultrabasics of the Onverwacht Series. In places, these rocks are exceptionally well-preserved, and it is hoped that field evidence, coupled with geochemistry, will provide valuable information of the early evolution of the earth's crust and mantle, and the differentiation of continents.

Prior to the renewed interest in the Barberton Mountain Land, there existed a detailed regional geological map and explanation of the area compiled by the South African Geological Survey (Visser et al., 1956). This early work provided a useful foundation upon which the subsequent studies have been built.

The geology of the Barberton Mountain Land is important primarily because of its great age, the volcanics and sediments having been intruded by granites having ages of 3000 million years. In spite of this great antiquity, the supra-crustal rocks are relatively unmetamorphosed over the majority of the area, and thus provide leading clues to deciphering some of the mechanisms operating in the ancient crust, as it existed in these times. The supra-crustal rocks are almost identical in type to those associated with younger geosynclines and emergent island arcs. They display isoclinal folding and ubiquitous thrusting. However, the source of the latest deforming stresses appears to have been the vast masses of intrusive granite that completely surround and intrude the rocks of the Mountain Land. These ancient granites do not have analogues in comparable younger geologic terrains, and it is suggested that their genesis is intimately related to the formation of the stable cratons. A further significance of these ancient rocks lies in the fact that very primitive forms of life have been identified in them.

REGIONAL SETTING AND GENERAL GEOLOGY

The Barberton Mountain Land forms one of the best developed and best preserved remnants of ancient Precambrian strata in South Africa. It occurs in the Eastern Transvaal Lowveld, immediately east of the younger cover of the Transvaal Drakensberg Escarpment, and occupies a wedge-shaped, triangular tract of country extending northeastwards from its broad base between Badplaas and Mbabane in the southwest, to its point of disappearance beneath the Lebombo Mountains on the Mocambique border near Komatipoort. Most of the area falls within the Transvaal, but the southeastern edge of the wedge straddles the Swaziland border and occupies the northwestern segment of the territory (see Figure 1). As the name implies, the best development of the Barberton Mountain Land occurs in the area flanking the town of Barberton.

Geologically the area is underlain by a variety of rock-types collectively grouped as belonging to the Swaziland System. The Onverwacht Series forms the oldest phase, and consists mainly of basaltic and ultrabasic rocks, together with siliceous sediments. The assemblage is essentially volcanic in origin, and has suffered considerable alteration in places, producing a variety of basic and siliceous schists. The rocks in the Series constitute the initial magmatic, or ophiolite, assemblage of the Swaziland geosyncline. The Fig Tree Series, which is essentially a sedimentary sequence, overlies the Onverwacht rocks, and consists mainly of fine-grained shales, grits, greywackes, banded cherts, and banded ironstones. Some lava horizons may also be developed in places. The sediments display characteristics of having been deposited in deep water by turbidity currents, and form an assemblage of rocks typical of the flysch sequence of geosynclines. Finally, the Moodies Series overlies the Fig Tree strata unconformably in places, and is made up of conglomerates, quartzites, shales, and a few bands of magnetic jaspilite and lava. These rocks provide evidence of shallow-water deposition, thus contrasting sharply with the essentially deep-water environment of deposition of the Fig Tree succession, and are likened to molasse sediments of geosynclines.

The Mountain Land is surrounded on all sides by a variety of granites and gneisses, some of which have produced profound metamorphic and structural alteration of the rocks of the Swaziland System (Hunter, 1965; Anhaeusser, 1966a; Roering, 1965, 1967; Anhaeusser and Viljoen, 1965; Urie and Jones, 1965; van Eeden and Marshall, 1965).

The Geological Survey (Visser et al., 1956) envisaged a further event — that of intrusion of a vast, differentiated suite of basic rocks, referred to by them as the Jamestown Igneous Complex. Subsequent studies have questioned this interpretation, and the proposal has been made that the Jamestown rocks merely represent the metamorphosed and structurally altered equivalents of Onverwacht rocks (Anhaeusser and Viljoen, 1965; Cooke, 1965; Anhaeusser, Viljoen, and Viljoen, 1966; and Viljoen and Viljoen, 1967).

The rocks of the Barberton Mountain Land have suffered a considerable degree of structural deformation, with the consequent formation of numerous fold and fault structures. Many structural data have become available, following the investigations of the Geological Survey (Visser et al., 1956; Ramsay, 1963; Herget, 1963; Anhaeusser, 1964, 1965, 1966b; Poole, 1964; van Vuuren, 1964; Viljoen, 1964; Roering, 1965; Urie, 1965).

A critical examination of the stratigraphy of the relatively small remnant of Archean rocks of the Barberton Mountain Land is indicated if we are to attempt construction of a model of the evolutionary events which led up to the complex development of a fold belt. Evidence, in the form of other small schist belt remnants, far removed from the Barberton area, tends to suggest a once extensive development of Archean rocks over the Southern African sub-continent. These remnants cannot, at present, be incorporated in the model, as very little is known about them. The model, of necessity, has to be constructed from all the available stratigraphic, sedimentological, and structural data that can be derived from the Barberton Mountain Land itself. The excellent exposure and preservation, coupled with the detailed knowledge that has recently been acquired from the area, have facilitated the construction of a model that appears, from the study of available literature, to be one of the most complete examples of an Archean geosyncline, or fold-belt, anywhere in the world. All the fundamental elements are believed to be contained in the Barberton fold belt, and it is contended that other, similar Archean belts represent more poorly exposed, more intensely metamorphosed, and less complete fragments in which all the elements might not necessarily have been present, and where the stratigraphic succession and structure are not as clear.

The view is held that the majority of Archean greenstone belts possess fundamentally similar elements (however obscure these may be), and experienced a broadly similar history to that of the Barberton Mountain Land, and that these belts may, in general, bear a close resemblance, or similarity, to the model formulated in this paper.

DETAILED DESCRIPTIVE STRATIGRAPHY OF THE BARBERTON MOUNTAIN LAND

A. THE ONVERWACHT SERIES

(a) Introduction

Lying at the base of the Swaziland System is a sequence of rocks comprising basic pillow lavas, ultramafites, and associated siliceous sediments. These rocks, collectively termed the Onverwacht Series, are best developed and preserved in the southwestern part of the Mountain Land, where they attain a thickness of over 35,000 feet. This essentially volcanic series can be traced right around the Mountain Land, and is everywhere in contact with the various intrusive granites which surround the whole area. Proceeding northwards, from the type-area in the south, the series thins rapidly, and also becomes more strongly thermally and dynamically metamorphosed. This metamorphism has resulted in the obliteration of many of the diagnostic lava structures, such as pillows and amygdales, which are so well-developed in the south. It has also led to the previous grouping of these metamorphosed basic rocks into the Jamestown Igneous Complex (Visser et al., 1956), which was considered to represent a post-Swaziland intrusive sequence of basic and ultrabasic rocks. As pointed out above, however, it has been shown (Anhaeusser and Viljoen, 1965; Anhaeusser et al., 1966; and Viljoen and Viljoen, 1967a and b) that these metamorphosed rocks, consisting essentially of amphibolites, and talc, talc-carbonate, and chlorite schists, are the equivalents of the Onverwacht Series, as defined in the south, and together they constitute the initial magmatic, or ophiolite, assemblage of the Swaziland geosyncline.

(b) Stratigraphy of the Onverwacht Series

In the type-area, in the southwestern part of the Mountain Land, the Series has been divided into three stages (Viljoen and Viljoen, 1967a). The Lower Onverwacht, or Theespruit Stage, which attains a thickness of 9,000 feet, consists of a sequence of metamorphosed basic lavas with interlayered siliceous sediments and salic tuffs, and occasional, thin, carbonaceous chert horizons and bands and lenses of serpentinized ultramafites. The main distinguishing feature of the Lower Onverwacht sequence is the occurrence of numerous siliceous, sedimentary or salic, tuffaceous horizons in the form of white, often friable, fine-grained quartz-sericite rocks, interlayered with the amphibolitized pillow lavas. Quartz and sericite are the main minerals in these rocks, but smaller amounts of andalusite, staurolite, biotite, muscovite, and sodic felspar are also present. Most of these horizons are capped by thin, black, carbonaceous chert bands. The associated lavas, which frequently contain signs of pillow structures and amygdales, are dark green to black in colour, the main minerals being actinolite, hornblende, grunerite and cummingtonite, with smaller amounts of quartz and sodic plagioclase. Chlorite and tremolite-actinolite are more common farther away from the granite contact. Numerous, thin, apparently interlayered, serpentinized ultrabasic bodies are typical of the lower part of the Stage. These are composed mainly of antigorite and tremolite, with relict olivine crystals and magnetite being fairly common.

The Middle Onverwacht, or Komati River Stage, attains a thickness of 11,500 feet in the type-area, and comprises an alternating sequence of amphibolitized pillow basalts and ultrabasic bands, with the exclusion of any siliceous material. The ultrabasics predominate in the lower half of the Stage, and a striking feature is the sympathetic thinning of individual ultrabasic and pillow basalt horizons. The ultrabasics are remarkably fresh looking and are usually dark blue to black in colour. They are, however, generally serpentinized to a greater or lesser degree, although, in many cases, only partly serpentinized olivine crystals form a mesh constituting much of the rock. Besides antigorite, which is the main mineral, varying amounts of tremolite, magnetite, clinopyroxene, and talc also occur. These rocks represent altered dunites. The main minerals encountered in the altered basalts are tremolite-actinolite, cummingtonite, chlorite, quartz, and felspar. Important in the Middle Onverwacht Stage are numerous intrusive bodies of quartz- and felspar-porphyry, which do not appear to be related to the surrounding intrusive granites, and are thought to represent an integral part of the Onverwacht succession.

The Upper Onverwacht, or Hooggenoeg Stage, reaches a thickness of 15,000 feet in the type-area, and consists of a sequence of pillow basalts with numerous, interlayered zones of andesitic to acid lavas, the latter often associated with well-developed chert horizons. The above assemblage constitutes the lower part of the Hooggenoeg Stage, and is unconformably overlain by a broad, irregular zone of "acid looking material" in the form of acid lavas and pyroclasts, salic tuffaceous material, and probable sediments. The lower part of the Hooggenoeg succession comprises a number of cycles, each commencing with a broad zone of andesitic to basaltic pillow lavas. The latter are followed by thinner, intermediate to acid lavas, and the cycles are frequently terminated by narrow, persistent, well-banded, and often carbonaceous chert horizons. Various calc-silicate and banded carbonate rocks are usually associated with these chert horizons. The predominant mineral in the more basic lavas is chlorite, accompanied by altered sodic plagioclase and carbonate. In the more acidic lavas, soda plagioclase, quartz, chlorite, sericite, and carbonate are found.

The Upper Onverwacht is developed in the southern part of the Mountain Land only, whereas the two lower stages can be recognized right the way around.

(c) Cyclic Evolution of the Onverwacht Series

One of the most striking features of the Onverwacht Series, is the ordered cyclic nature of the vulcanicity and sedimentation. The cyclic nature of deposition is perhaps best displayed in the Onverwacht type-area in the Komati River Valley (Viljoen and Viljoen, 1967a and b).

At least 10 major cycles and up to 20 minor cycles are developed in the Lower Onverwacht Stage. These cycles are characterized dominantly by the occurrence of basic and ultrabasic lavas, the former being in ascendancy over the latter. The lavas give way to rather thin salic tuffs (now quartz-sericite schists), the whole cycle being terminated by the deposition of narrow chert bands in quiescent conditions before the onset of the subsequent cycle. One to five lava flows, varying in thickness from 5 to 300 feet, constitute the extrusive volcanic phase of a particular cycle. In the Middle Onverwacht Stage, the cyclic nature of the vulcanicity is manifested by alternating pillow lavas and ultrabasics. In the Upper Onverwacht sequence the cyclic nature of the vulcanicity and sedimentation is remarkably well-demonstrated, and at least five cycles, varying in thickness from 500 to 5000 feet, and diminishing in size upwards, have been mapped. The latter cycles are characterized by the initial outpouring of basic to intermediate lavas (5 to 20 flows or more), followed by a thin zone of acid lava (one to three flows) which, in turn, is followed by the deposition of a substantial zone of black and white, sometimes slightly ferruginous, banded chert. Judging by the thickness and extent of these cherts, they were deposited over fairly long periods of quiescence before the initiation of the following cycle. The upper division of the Upper Onverwacht consists of a huge mass of salic volcanic sediment and lava overlain by a very substantial banded black and white chert (also sometimes slightly ferruginous). This cycle, characterized by a marked period of quiescence during which the chert was deposited, marks the end of the Onverwacht Series, as defined in the type-area in the southwestern part of the Mountain Land.

(d) The Environment, Conditions of Deposition and Geological Significance of the Onverwacht Series

Most geosynclines are characterized by an initial volcanic episode during their early evolution. Abundant outpourings of lava, known as ophiolites, are characteristic. These rocks are liable to metamorphism and structural disturbance during the subsequent orogenic phase of the geosyncline, as well as during the intrusion of granite (in the case of the Barberton Mountain Land, at a much later date). These processes give rise, as a result, to a complex association of basic rocks — the universal "greenstones" of English geologists, and the "grunes gestein" and "pietri verdi" of European geologists. Despite the severe structural disturbances which most ophiolite assemblages have undergone, three main rock-types — basic lavas, ultrabasics, and cherts — emerge as fundamentally important units. The recognition of the association of these rocks by Steinmann (1905) was of classic importance, and subsequently became known as the Steinmann Trinity. Most workers have employed the presence of pillow structures in the lavas as evidence of submarine extrusion. The cherts, on the other hand, are thought to represent chemical precipitates, deposited during periods of quiescence between the outpourings of lava. The origin of the ultrabasic rock (the so-called Alpine peridotites) remains, however, one of the most enigmatic of geological problems.

From the description of the stratigraphy of the Onverwacht Series, presented above and described fully by Viljoen and Viljoen (1967a), it is abundantly clear that the rocks of the Series have their more recent analogues in the ophiolite assemblages of geosynclines and present-day emergent island arcs. This being the case, it is conceivable, and likely, because of the huge thickness of the sequence and the occurrence of chemically precipitated sediments, that the environment of deposition of the Onverwacht Series was that of a deep-sea trough, or graben, in a crust which was only a fraction of its present thickness.

Despite the age of the rocks, a number of factors, including the relatively unaltered nature, the low degree of thermal and dynamic metamorphism, and the excellent exposures, makes the southern part of the Mountain Land, in the Komati River Valley, a remarkable area for the study of a complete ophiolite sequence. Many of the problems associated with ophiolites of more recent geosynclinal belts, and the problems of the greenstones of the shield areas may find a ready explanation in the model presented by the Onverwacht Series. Initial results (Viljoen and Viljoen, 1967b) indicate, for example, the close association of cherts with acid lavas or acid tuffs, and a relationship between the silica (volcanic in origin) content of the water and the deposition of cherts. Furthermore, mounting evidence from the most undisturbed portions of the Mountain Land indicates the possibility of widespread outpourings of ultrabasic magma in the form of flows or extrusive pods which, in some places, show distinct signs of differentiation. Many apparently intrusive ultrabasic bodies are thought to represent tectonically transported portions of the Onverwacht sequence.

In addition, the tholeiitic nature of many of the lavas is becoming apparent. These low potassium tholeiites appear to have their modern counterparts in the present-day ocean basins (Engel et al., 1965; Engel, 1966), and the "primitive" (uncontaminated) nature of the volcanics is attributed to the passage of magma through a relatively thin sialic crust. Chemical data on these lavas should, therefore, give valuable information as regards the composition of the upper mantle of the earth some 3.4×10^9 years ago.

B. THE FIG TREE SERIES

(a) Introduction

Immediately and conformably overlying the predominantly volcanic successions of the Onverwacht Series is a group of rocks composed essentially of siliceous chemical precipitates, together with a great accumulation of pelitic sediments. Where best developed in the Ulundi Syncline, north of Barberton, this Fig Tree succession has been subdivided into a lower division, which includes rocks that are at times difficult to distinguish from the metamorphic products of the underlying Onverwacht Series; a middle division which includes the typical Fig Tree rocks, notably turbidites (greywackes) and banded cherts; and an upper division, characterized by a reworked, unconformable grit horizon, more greywackes, and a volcanic horizon. The Fig Tree rocks have recently yielded evidence of primitive life dating back more than three billion years.

(b) Distribution of the Fig Tree Series

Rocks belonging to the Fig Tree Series are best developed towards the interior regions of the Mountain Land, where they are sandwiched between the underlying Onverwacht sequence and the overlying group of Moodies strata. The Fig Tree sequence attains its fullest development northeast of Barberton, in the Ulundi Syncline, where Ramsay (1963) estimated a total thickness of at least 10,000 feet for the tectonically flattened strata. Fig Tree rocks are also well-developed in the area south of Malelane, in the area southwest of Barberton, and in the northwestern segment of Swaziland. The resistant cherts of the Series build lofty mountain chains while the softer shales occupy deeply incised V-shaped valleys.

(c) Rock Types and Stratigraphic Sub-Divisions

The Fig Tree Series is composed of a highly varied group of sediments composed essentially of banded cherts, banded ironstones, banded jaspers, shales, greywackes, quartzites, grits, and conglomerates. The Zwartkoppie Stage, or lower divisions of the Fig Tree Series, consists of three main members, viz., talc-carbonate rocks, quartz-sericite rocks, and banded chert. At present, it is not certain whether the Zwartkoppie Stage forms the true base of the Series. In the southwestern parts of the Mountain Land, shales and cherts of the Fig Tree Series overlie either acid or basic volcanic rock-types, and at no place can the typical assemblage of the Zwartkoppie Stage be identified in contact with the Onverwacht Series. In the Ulundi Syncline, carbonate-chlorite-talc rocks occupy the lowest stratigraphic position, and occur in the cores of anticlinal structures (van Vuuren, 1964). Herget (1963) noted serpentinites occurring as cores in the talc-carbonate schists of the Zwartkoppie Stage in the Montrose area, southwest of Barberton. Van Vuuren (1964) showed that the Ni and Cr content of these carbonate-bearing rocks is suggestive of their being of volcanic origin, and suggested that they had moved into the anticlinal cores by means of tectonic transport, i.e. the upfolding of the volcanic rocks of the underlying Onverwacht Series. The 'Zwartkoppie Horizon' occurs as a marker in the Zwartkoppie Stage. In places the horizon is comprised solely of massive and banded chert, but well-bedded cherts and black shales are also developed. In addition, ferruginous shales and banded cherts, referred to as "banded ironstones", occur here, as well as higher in the succession. Koen (1947) concluded that the greenschists in the Zwartkoppie Stage are markedly similar mineralogically to greywackes, and that they owed their origin to intense mylonitization of greywackes and shales, sandwiched between the competent banded cherts and the underlying carbonate rocks. Van Vuuren (1964) recorded a thin but persistent, sulphide band at the top of the Zwartkoppie Stage, the areal extent of which suggested a syngenetic origin with the banded chert. Overlying the 'Zwartkoppie Horizon' is a carbonate-bearing sandy phyllite, followed by an oolite layer.

The middle Fig Tree sequence consists of a very thin succession of alternating greywackes, shales, and grits, with thin chert bands. Higher in the sequence more greywackes, shales, banded ironstones, and gritty greywacke layers are developed.

The upper Fig Tree sequence consists of still more greywackes and shales, banded chert, banded ironstone, and grits. At the top of the succession is a felspathic, tuffaceous greywacke. A greywacke conglomerate is also locally developed.

The mineralogical composition of the greywackes throughout the Series indicates material clearly derived from basic and acid volcanics, as well as from crystalline bodies such as granites, gneisses, or migmatites.

(d) Evidence of Primitive Life-Forms

The cherts and shales of the Fig Tree Series have yielded evidence of very primitive life-forms dating back more than 3000 million years. Ramsay (1963) reported oolitic structures, resembling primitive algae (Calcisphaera) from the Sheba Mine area. Hoering (in: Pretorius, 1965) reported the presence of straight-chained hydrocarbons with 16 to 24 carbon atoms in Fig Tree shales. These, he suggested, were diagnostic of biologically produced petroleums. More recent studies by Pflug (1966) and Barghoorn and Schopf (1966) have revealed microfossils preserved mainly in the dark banded cherts. Pflug (1966), furthermore, suggested that the algal bodies were able to precipitate metal salts, with cations such as copper, iron, and calcium, from water, by the action of their life processes. Biological processes of such a type, he believed, could have played an important factor in the formation of sedimentary iron formations.

Cloud (1965), in discussing the Gunflint microflora from Ontario, presented similar ideas concerning the origin of Precambrian banded ironstone formations. The Gunflint thallophytes at 1.9×10^9 years were, up to the time of the discoveries of similar fossil organisms in the Barberton cherts by Pflug (1966) and Barghoorn and Schopf (1966), the oldest recorded structures closely resembling specific living organisms. Cloud (1965) suggested that the thallophytes may have been photosynthesizers which attached any free O_2 that was generated to some convenient oxygen acceptor in the hydrosphere. Ferrous iron, transported to the basins of deposition in reducing surface waters, would have been such a convenient acceptor for any available O_2. The oxidized iron may then have formed the typical banded ironstone formations. This would explain the apparently anomalous situation of ferric (banded ironstone) formations being deposited in an early atmosphere that has widely come to be regarded as of a reducing type (Rubey, 1955; also: Symposium on the Evolution of the Earth's Atmosphere, 1965).

(e) Sedimentation Pulses of the Fig Tree Series

The Fig Tree succession can broadly be divided into three phases or pulses of sedimentation, which cannot be defined as clearly as those of the underlying Onverwacht rocks. At the base of the Series the rocks are composed essentially of a considerable thickness of precipitated cherts, banded chert, shales and other fine argillites of the Zwartkoppie Stage. This period of quiescence seems to have been carried over from late Onverwacht times as many of the rock-types in the lower portion of the Zwartkoppie Stage are similar in character to the underlying, essentially volcanic assemblages.

The next pulse resulted in the rapid accumulation of the "greywacke suite" and it began with the deposition of coarse greywackes, grits, and shales, with some minor chert interlayers. Later in the sequence, the greywackes become much finer than lower down, and there is more shale and numerous banded chert and banded ironstone layers towards the top.

The final, broadly recognizable sedimentation pulse of the Fig Tree Series again began with the accumulation of grits and coarse greywackes and, at the end of Fig Tree times, the deposition took place of a tuffaceous, felspathic greywacke and a greywacke conglomerate, the latter merging in places with the basal conglomerate of the Moodies Series.

(f) Environment and Conditions of Deposition of the Fig Tree Series

The greywacke suite, or flysch, is a well-established facies of a geosynclinal environment, and is generally closely associated with spilitic and pillowed greenstones. In the Barberton Mountain Land, the Fig Tree assemblage of rocks appears to conform with this pattern, being closely associated in time with the Onverwacht volcanic successions. Typically, the Fig Tree rocks consist of a considerable thickness of argillites. These are essentially clastic, although there were apparently quieter periods when bedded cherts and banded ironstones were also laid down, particularly in the early stages of the sequence. As pointed out previously the presence of primitive photosynthesizing organisms in the early depository probably played an important part in the formation of the banded ironstones.

Deposition of the sediment was nearly continuous and uninterrupted, with the bedding being rhythmic and well-marked. Graded bedding is frequently seen in the grey-wackes, microbreccias and grits, and poorly sorted greywackes reflect incursions of slump-generated turbidity flows. A great variety of sedimentary structures is of use in establishing the environment and style of deposition of these rocks. Slump bedding, current marks, load-casts, flute-casts, convolute bedding, and graded bedding are characteristic of the sequence. The rhythmically bedded formations of alternating shales and well-graded greywackes led Kuenen (1963) to classifying the Fig Tree Series as a turbidite formation. He recognized numerous sedimentary structures indicating that the greywackes were formed by turbidity currents. Both van Vuuren (1964), who identified flute-casts, load-casts, and possible slide-marks in the greywackes of the Ulundi Syncline, and Herget (1963), who observed flute-casts and convolute-bedding in the Montrose area, confirmed Kuenen's earlier findings, thus making the Barberton turbidity formations the most ancient yet recorded anywhere in the world.

The gradual increase in the coarseness of the sediments is evident towards the top of the Fig Tree sequence, with grits, coarse greywackes, and minor conglomerates making an appearance. The conclusions that can be drawn, therefore, suggest that an extremely thick formation of sediments accumulated rapidly in a deep-water marine environ-ment. Texturally and mineralogically, the sediments are very immature, and must have been derived from erosion of a high land-mass believed, in part, to consist of a crystalline terrain, as well as of strata deposited earlier in the same geosyncline, or trough.

C. THE MOODIES SERIES

(a) Distribution of the Moodies Series

The Moodies Series follows, in places conformably, in others unconformably, on the underlying Fig Tree succession. It consists mainly of arenaceous rocks, with minor sandy-shale horizons and a characteristic and persistent basal conglomerate. The rocks of this Series cover large areas, especially in the interior of the Mountain Land, where the formations build lofty ranges responsible for much of the scenic beauty of the area. Although the Series has a wide distribution, particularly in the central and eastern portions of the area, the Moodies rocks are generally located in synclines that are separated from each other by large, longitudinal thrust faults that trend in a northeast-southwest direction and which divide the Mountain Land into a number of fault-bounded "cells". The Lily, Eureka, Saddleback, and Stolzburg Synclines are but a few examples of major structures in which Moodies rocks are preserved.

(b) Lithology of the Moodies Series

The Moodies Series is composed predominantly of psammitic and psephitic sediments. The dominant rock-types are boulder beds, conglomerates, quartzo-felspathic sandstones, sub-greywackes, siltstones, and shales, with local developments of magnetic banded ironstones and jaspilites. Also included in the stratigraphy of the Moodies rocks of the Eureka and Saddleback Synclines is a thin amygdaloidal lava horizon, now mainly amphibolitized.

The conglomerates consist of well-rounded pebbles and boulders. The conglomerate is polymictic, containing pebbles of black and white chert, banded ironstone, jasper, grit, granite, quartzite, micropegmatite, quartz porphyry, shale, and quartz-sericite-schist. In addition, pebbles of conglomeratic material have also been found in the basal conglomerate of the Eureka Syncline. The pebbles occur in an arenaceous matrix of felspathic quartzite, greywacke, and sandy shales. The conglomerate is generally followed by a carbonate-rich quartzite.

The most complete succession of Moodies strata is preserved in the Eureka Syncline, where it has been broadly sub-divided by Visser et al., (1956) as follows :

Upper Shale
Upper Quartzite (Baviaanskop)
Middle Shale
Middle Quartzite (Joe's Luck)
Lower Shale
Lower Quartzite
Basal Conglomerate

The thickness of sediments along the southern limb of this syncline is about 10,300 feet, of which argillaceous rocks represent 46 per cent. Along the northern limb the thickness is approximately 6,500 feet, of which 75 per cent consists of argillaceous material. Magnetic shales and jaspilites occur near the base of the Lower Shale horizon. The Middle Shale also has a magnetic shale and jasper horizon, as well as a thin band of amygdaloidal lava. The Upper Shale is capped by a thin, small-pebble conglomerate, with a matrix of coarse, gritty sandstone. The three quartzite horizons have locally developed conglomeratic bands, but these never approach the dimensions and character of the basal conglomerate. The Moodies rocks of the central portion of the Mountain Land appear to consist of vast thicknesses of quartzitic material, and it is not possible to correlate these masses with the Moodies stratigraphy as defined above. In Swaziland, only the basal conglomerate and the Lower Quartzite are represented.

(c) Sedimentation Pulses of the Moodies Series

There appear to have been several stages of sedimentation of the Moodies succession. In the type-section of the Eureka Syncline, three main pulses can be recognized. The first of these began with the deposition of the basal conglomerate, followed by calcareous orthoquartzites and felspathic quartzites, and ended with shales and banded magnetic jaspilites. The presence of calcareous quartzites alternating with impure limestone and marble bands (orthoquartzite-carbonate facies) in the lower portion of the Moodies Series is suggestive of a shallow-water depositional environment, marginal to a low-lying stable land surface.

The next pulse began with quartzite development (only locally conglomeratic), followed by a minor period of volcanism and a second, banded magnetic jasper horizon, together with shales. The third and last pulse began with minor (local) conglomerate and quartzite development, which was followed by an alternating sequence of shales, subgreywackes, grits, and, finally, a small-pebble conglomerate.

Each pulse appears to have started with a great influx of coarse detritus. Gradually, the depositional pattern trended towards an environment that allowed for the settling out of shales, fine argillites, and chemically precipitated jaspilites and banded ironstones.

(d) Conditions of Deposition of the Moodies Series

All the quartzites show abundant cross-bedding and ripple-marks. Mud-cracks frequently occur in the shales. In the Eureka Syncline, trough cross-bedding is particularly prominent in some areas, and appears to be indicative of transportation of sediments in braided stream channels. Graded bedding and cross-bedding can frequently be used to determine the direction of younging of the sediments. Bedding in all rock-types is clearly evident, although in some of the shales in the Eureka Syncline it is, at times, obscured by a strong cleavage developed oblique to the stratification. The sedimentary features, together with the development of conglomerates, which locally display poor sorting, are indicative of deposition in shallow water. This contrasts sharply with the deep-water sedimentational environment of the Fig Tree shales, banded cherts, and greywackes.

Much of the Moodies sedimentation can be ascribed to the denuding of previously deformed Fig Tree and Onverwacht Series rocks. Evidence that the Fig Tree succession had been subjected to folding prior to the deposition of the Moodies Series has been extended by Visser et al., (1956) who reported the presence of contorted banded chert pebbles in the Moodies conglomerates. These contorted banded cherts are, however, not entirely diagnostic of an earlier deformation, for they could equally well have been formed by slumping within the depository itself. The polymictic nature of the basal conglomerates is ascribed to the influx of pebbles of black chert, quartz porphyry and quartz-sericite-schists from denuded Onverwacht successions, while the banded ironstone, jasper, grit and banded chert pebbles could have been derived from the Fig Tree Series. Furthermore, the presence of granitic, micropegmatitic and quartz porphyry pebbles are ascribed to erosion of an elevated granitic terrain close to the Mountain Land. This terrain is also regarded as the basement upon which the Swaziland System sediments and volcanics were deposited. Microscopic examination of the sediments in the Moodies Series of the Eureka Syncline has disclosed the presence of abundant sodic and potassic felspar in the form of oligoclase, albite, microcline, and perthite, prevalent particularly in the impure quartzites and sandstones. These minerals are all abundantly encountered in the granite-gneiss terrain of the Eastern Transvaal Lowveld.

Although much of the material in the Moodies succession appears to be essentially the product of a high-energy turbulent environment, there must have been short periods of quiescence in which the banded magnetic shales and jaspilites and other finely laminated shales were deposited. The depositional cycle was also interrupted by a period of mild volcanism, during which time the narrow band of amygdaloidal lava was extruded.

The clastic sediments of the Moodies Series, consisting mainly of conglomerates, quartzites, sandstones, and shales, can be defined as a molasse association. Furthermore, the overall character of the Moodies rocks conforms to the molasse requirements outlined by Pettijohn (1957). These requirements include the presence of calcareous sands and shales, marked cross-bedding, and sediments formed in varying environments, that are differentiated texturally (and hence chemically and mineralogically) according to the energy controls of the depositional agencies. In addition, the molasse of the Moodies frequently transgresses the flysch of the Fig Tree Series and the underlying ophiolite sequence of the Onverwacht volcanic assemblage of the Barberton geosyncline.

D. DYKES

(a) Introduction

Hypabyssal rocks, mainly in the form of dykes, are prolifically distributed over the entire area of the Barberton Mountain Land, but attain their greatest development in the areas underlain by granitic rocks. Practically all the dykes are vertical, and many give rise to striking topographical features. The dykes are of several varieties, each of which tends to prefer a certain well-defined strike direction. The dykes vary widely in age and in mineralogical and chemical composition. Sheet- or sill-like intrusions occur, but are less frequent than the dykes.

(b) Structural Control of Dykes

The dykes generally conform to definite strike directions. A prominent direction is from 30° to 35° west of north to approximately northwest (Visser et al., 1956). A second direction is roughly at right angles to the former, i.e. from 30° east of north to northeast. Some dykes trend north-south, others parallel the strike of the formations, and yet others deviate completely from these directions. Zones of faulting and jointing appear to have had the major controlling influence on the occurrence and trend of the dykes.

(c) Dyke Varieties

1. Early Dykes in the Migmatites and Gneisses

Highly deformed dykes occur in the Nelspruit Granite, the Badplaas Granite, and in the Ancient Gneisses of Swaziland. These dykes are often folded, the axial planar structure of the migmatites being identical to the axial plane of the dykes (Roering, 1967). The dykes are locally cross-cut and injected by the granitic matrix into which they at one time intruded. The dykes are now amphibolitized.

There are several ages of dykes; some have been folded, others have not, but both types have been involved in the palingenesis of the surrounding migmatitic and gneissic material. The ancient gneisses and associated dykes were possibly reactivated during the G.4, or synorogenic, granitic cycle which is dated at 3070 ± 60 m.y. by Allsopp et al. (1962). The inference to be gained from the involvement of the early dykes in the migmatite-gneiss palingenesis is evidence in support of this terrain being representative of an ancient, pre-Swaziland System basement.

2. Dykes Later than the Swaziland System

Dykes later than the Swaziland System have been divided into several categories (Visser et al., 1956) which reflect the age relationships between the dykes themselves and the various stratigraphic successions of the Mountain Land and the surrounding areas.

The dykes have been grouped as follows :

1. intrusions older than the Moodies Series
2. intrusions older than the Godwan Formation
3. intrusions younger than the Transvaal System
4. late dykes of Karroo dolerite.

The majority of dykes in the area are diabasic in composition. Some of the larger diabase bodies have differentiated into a wide variety of rock-types. These include peridotite, olivine gabbro, quartz gabbro, quartz diorite, and granophyric end-members with micrographic intergrowths of quartz and felspar. Some diabase dykes are porphyritic and contain large felspar phenocrysts. Pyroxene-amphibole dykes and ultra-basic dykes occur less frequently. Karroo dolerite dykes mark the last phase of igneous activity in the area.

E. GRANITES

(a) General

The supra-crustal rocks of the Mountain Land are surrounded by granites which, in all cases, are clearly intrusive, and which are also responsible for contact metamorphic effects. The contact rocks are most frequently members of the Onverwacht Series (Jamestown of the Geological Survey). These rocks, generally varying from basic to ultrabasic types, were considered to have acted as barriers or basic resisters against granitization, thus preserving the sediments higher up in the stratigraphy from metamorphism (Visser et al., 1956). However, if the basement on which the Onverwacht rocks were deposited were granitic and made reomorphic, to produce diapiric intrusive domes, the latter would be draped by Onverwacht rocks in a manner similar to the mantled gneiss domes of Eskola (1948).

(b) Granite Classification in Swaziland

Hunter (1965) placed the granitic rocks of Swaziland in a coherent sequence, based on the concept of cycles. He recognized an Ancient Gneiss Complex, comprising an assemblage of gneisses and granulites, with recognizable relics of meta-sediments. These rocks are intimately associated with the Granodioritic Gneisses, which are thought to be derived from the former group by processes of granitization. Both groups are well-foliated, and represent members of the earliest cycle.

The next cycle began with geosynclinal conditions and the deposition of the Swaziland System on rocks belonging to the first cycle. The first deformation of the orogenic phase of this cycle led to the formation of the Synorogenic Granodiorites and Granites. These rocks vary from quartz diorite to leucocratic granodiorite. Locally, there is evidence of complete mobility, with the rocks displaying intrusive contacts and randomly oriented amphibolite fragments. In addition, rocks of this group reveal a definite foliation which is also present in the rocks belonging to the first cycle. Hunter (1965) concluded that the earlier gneisses also reveal an earlier deformation, and that the synorogenic granites crystallized from a magma.

The Late Orogenic Granites are distinguished from the former types in that they are generally devoid of planar or linear fabrics, except close to the margin, where they intrude the supra-crustal rocks. They are typically massive, dark grey, medium-grained granites and granodiorites, the latter being quantitatively less abundant than the former.

The association of pegmatites with this late granitic variety is frequent, and most of the mineralization of Swaziland (Au, Sn, Nb, Ta, Sb, Wo, and Mo) is related to this granite event.

A fundamental feature, noted by Hunter (1965), is that the Late Orogenic Granites occupy a higher position in space than do the previously described granites. They are thus sheet-like in shape.

Several large plutons of coarse-grained porphyritic granite occur in the territory, and reveal sharply transgressive contacts. These Post-Orogenic Granites are not all of the same age, and were emplaced when the Swaziland area ceased to be part of a mobile belt. They were thus intruded after the close of the second cycle, which ended with the emplacement of the Late Orogenic Granite.

(c) Granite Classification in South Africa

A less rigorous breakdown of granites in South Africa has led to the recognition of a number of distinct types, viz. the Kaap Valley, Nelspruit, Nelshoogte, M'pageni, Salisbury Kop, and Dalmein granites.

The Kaap Valley Granite forms a huge pluton surrounded by Swaziland rocks (Figure 2). It is essentially a hornblende granodiorite, often containing biotite. A distinct, foliated fabric is developed close to the contact area with the supra-crustal rocks. The granite is clearly intrusive into the Swaziland rocks. The Nelspruit Granite is the name given to vast areas of granitic rock that are distinct from the other varieties. It is made up of highly variegated rock-types, ranging from homogenized granites without any visible fabric, through gneisses, to complex migmatites. On the northern side of the belt of supra-crustal rocks, this granite reveals a homogenized phase, several thousand feet wide, which is confined to the contact zone. Pegmatites are clearly related to this homogenized phase. The Nelshoogte Granite, like the Kaap Valley Granite, forms a pluton north of Badplaas, that is surrounded by Swaziland System rocks in the east, but is covered by younger escarpment formations in the west. It is essentially a granodiorite, containing biotite, and has myrmekitic intergrowths of quartz and felspar. The granite is intrusive into the Swaziland System rocks and possess a well-defined foliated fabric near the contacts.

The M'pageni Granite occurs as a discordant pluton in Nelspruit Granite. It is characteristically a coarse-grained granite somewhat similar to the post-orogenic granites described by Hunter (1965). The Salisbury Kop Granite is characterized by having no visible foliation, and is somewhat similar in appearance to the M'pageni Granite, in places. It is generally a medium- to coarse-grained granite which intrudes Swaziland rocks. Its exact relationship to the Nelspruit Granite is not established, as yet. Van Eeden and Marshall (1965) consider this granite to be a reomorphosed equivalent of the basement on which the supra-crustal rocks were deposited. The writers, however, are of the opinion that this body is a younger granite pluton, similar to the M'pageni and post-orogenic granites (formerly known as the G.5 granites), described by Hunter (1961, 1965). The granite is typically homogeneous, and has a narrow chill-phase of aplitic and alaskitic granite around the edges, in contact with the Swaziland System rocks (Viljoen and Viljoen, 1967b). Another, essentially similar, post-orogenic granite pluton, called the Dalmein Granite, invades the Onverwacht successions in the Komati River Valley (Figure 2), and truncates the sequence abruptly. The granite is a coarse-textured rock, and possess no contact foliation (Viljoen and Viljoen, 1967b).

Table 1 compares the three major groups of granitic rocks in Swaziland and South Africa, and includes the interpretation currently favoured by the authors.

TABLE 1

A Comparison of the Three Main Groups of Granitic Rocks – Previous Views and Present Interpretation

SWAZILAND Hunter (1965)	SOUTH AFRICA (pre-1967) Ramsay (1963); Anhaeusser (1964, 1966a); Anhaeusser and Viljoen (1965); Roering (1965); Viljoen (1964).	PRESENT PAPER
3. Post-Orogenic Granites	M'pageni and Salisbury Kop Granites	Younger high-level porphyritic granites, such as the M'pageni, Salisbury Kop, Dalmein, and G.5 (or Post-Orogenic) of Swaziland; (granites non-foliated; cut cleanly across the trends of the supra-crustal rocks).
2. Late-Orogenic Granite Synorogenic Granodiorites and Granites	Mobilized border-phase of Nelspruit-type Migmatites and Gneisses Kaap Valley Granite and others – representing reomorphism of the basement gneisses	3000 m.y. granitic episode super-imposed on an already orogenically deformed Swaziland System. - invasion of diapiric granite bodies such as the Kaap Valley Granite, Nelshoogte Granite etc.; (granites foliated; responsible for structural disturbance of the supra-crustal Swaziland System rocks).
1. Granodioritic Gneisses Ancient Gneiss Complex	Basement represented by Nelspruit-type Migmatites and Gneisses	Basement Migmatites and Gneisses.

F. STRUCTURE OF THE BARBERTON MOUNTAIN LAND

(a) General

In broad terms, the Barberton Mountain Land represents a strongly deformed, synclinal, boat-shaped remnant of layered, supra-crustal rocks, intruded and completely enveloped by a vast and complicated granitic terrain. This synclinorial keel has a length of 80 miles, and a strong east-northeasterly trend. It forms a narrow, elongated triangle, tapering gradually from a maximum base width of 32 miles in the south (between Badplaas and Forbes Reef), to five miles in the extreme northeast, near Hectorspruit, where it disappears under a younger cover of Karroo sediments. The average width of the belt (between Barberton and Pigg's Peak) is 17 miles.

(b) Arcuate Schist Belt Remnants

Strikingly apparent from the structural map (Figure 3) are the generally arcuate, narrow, tapering protruberances of layered rocks which trend in all directions away from the main, east-northeast-trending grain of the triangular keel. These protruberances, or schist belts, attain their best development on the northwestern, western, and southwestern sides of the Mountain Land, but are also present as much smaller and generally more conformable features along the other contacts of the Mountain Land. The most spectacular of these is the Jamestown Schist Belt which trends in a northwesterly direction from Noordkaap to Kaapsehoop. It is slightly arcuate, being concave towards the south, i.e. towards the Kaap Valley Granite. The belt has a strike length of about 22 miles, from Noordkaap to the Transvaal Drakensberg Escarpment, where it disappears under the younger, flat-lying quartzites of the Black Reef Series and lavas of the Godwan Series. Another conspicuous, tapering, triangular belt is the Nelshoogte Schist Belt on the southern side of the Kaap Valley Granite. It also trends in a northwesterly direction, and is slightly arcuate. Some of the most spectacular arcuate schist remnants occur on the south side of the Mountain Land, between Badplaas and Oshoek. Although much smaller than the two above-mentioned belts, numerous coalescing tongues form interferring arcuate structures, as can be well seen north of Lochiel (Figure 3).

A significant feature of these relatively small, arcuate belts is that almost all of them consist of metamorphosed basic volcanics and ultrabasics of the Onverwacht Series (particularly the two lower stages). This also applies to the outlying, small remnants within the granites near Alkmaar, in the area north of Badplaas, in the area of the Kruger National Park, and in the region extending from Kaapmuiden towards the Consort Mine.

(c) The Relationship of the Arcuate Belts to the Surrounding Granites

Of importance in connection with the origin of the arcuate belts is the nature and disposition of the surrounding granites. In the southwest, where the arcuate belts are best developed, the granitic terrain consists of a series of generally elliptical or circular, discrete, homogeneous granite plutons or domes, varying in diameter from 25 miles (long axis of the Kaap Valley Granite) to one mile. These granites are intrusive into the Onverwacht lavas and, although not always strikingly apparent, are clearly transgressive in many cases. The plutons are partly separated from one another by the arcuate tongues of basic material, and have clearly been responsible for the strong thermal and dynamic metamorphism of the latter, as well as for their present structural disposition. Evidence of this is afforded by the development of a strong metamorphic fabric in the meta-volcanics, which closely parallels a similar foliation in the adjacent granites. The latter foliation is caused by the alignment of platy minerals, and is accentuated by the alignment of metamorphosed basic xenoliths.

Clearly, the metamorphosed arcuate belts have originated as a result of the updoming, and/or intrusion, of more-or-less discrete, and partly interferring, granite domes of different sizes, which have moulded the meta-volcanics to fit their outlines. It follows that the amount of arcuation and, to a lesser extent, the size of every basic schist belt, is a direct function of the size (radius) of the individual, adjacent granite plutons. Thus, the largest and least arcuate of the belts, viz., the Jamestown Schist Belt and the Nelshoogte Schist Belt, surround the largest granite pluton (the Kaap Valley Granite). The smallest and most arcuate belts, viz., those just north of Lochiel, partly envelop the smallest plutons.

Although the Kaap Valley Granite is the largest of the obvious granite plutons, and the Jamestown Schist Belt is the largest of the arcuate belts, it is the opinion of the authors that the entire eastern contact of the Mountain Land has been gently arcuated by the emplacement of an even bigger granite body. In its general characteristics and relationship to the Mountain Land, this granite, the so-called synorogenic granite of Swaziland, is closely analogous to the smaller granite plutons mentioned above. It represents a very large equivalent of the latter, and an idea of its dimensions can be gained from the gentle arc of curvature of the whole eastern contact of the Mountain Land.

The northern granite contact is of interest in that it represents a zone of strong shearing — a phenomenon which continued after the consolidation of the narrow belt of intrusive granite along this contact. This is evidenced by the cold mechanical grinding which these granites suffered following crystallization.

(d) Major Fold Structures of the Barberton Mountain Land

Conspicuous within the main northeast-trending keel, and constituting the main structural features of the Mountain Land, are a series of well-developed, predominantly tight, synclinal folds. These trend in a general northeasterly direction, and have steeply dipping limbs, often overfolded to the northwest. The axial planes may be locally folded or warped, as in the case of the Eureka and Ulundi synclines. Other prominent, northeast-trending synclines include the Saddleback, Stolzburg, and Kromberg synclines. One major exception is the Jamestown Syncline which trends northwest (parallel to the superimposed axial plane of the inflected Eureka and Ulundi synclines). This syncline occurs in the largest arcuate schist belt in the Mountain Land.

Anticlinal structures between major synclines are generally absent, having been faulted out in many cases. If anticlines are present, they are very poorly developed in comparison to the adjacent synclines. Two conspicuous anticlines are the Steynsdorp Anticline, in the Komati River Valley and the Stentor Anticline, to the southeast of Kaapmuiden. As will be shown later, these anticlines have a different origin to those between the major northeast-trending synclines. A large, open anticline (the Onverwacht Anticline) forms a major structural feature in the southern part of the Mountain Land. Unlike the tight, east-northeast-trending, isoclinal fold structures to the north, and those flanking this fold structure on the east and west (Stolzburg and Kromberg synclines), the Onverwacht Anticline is a broad, open fold, and, as such, poses certain structural problems.

(e) Major Faults

The Barberton Mountain Land has a striking array of major east-northeast-trending faults. These extensive longitudinal strike faults divide the Archean fold belt into a series of long, narrow blocks, trending east-northeastwards, parallel to the regional grain. They are generally of a high-angled thrust type, and often occupy positions between adjacent synclines. Good examples are the Barbrook and Sheba faults, which are of great economic importance, being closely associated with major gold deposits. Another type of fault with which mineralization is also often associated occupies the contact between zones of incompetent and relatively more competent rock-types. These are more in the nature of zones of strong shearing, rather than major thrust dislocations. Examples of this type are the Lily Fault and the Consort "Contact" in the north, and the Violet Fault in the southern part of the Mountain Land. Of special note are the Kaap River and Albion faults in the Jamestown Schist Belt. Unlike the majority of other faults which follow the east-northeast grain of the Mountain Land, these trend northwestwards, parallel to the trend of the Jamestown Schist Belt itself. The Kaap River and Albion faults occupy positions in the north and south limbs, respectively, of the Jamestown Syncline. Both converge towards the west, and it is tentatively suggested that they join one another, and represent an early strike fault that has been folded together with the strata of the Jamestown Belt. A somewhat similar situation exists in the southwestern part of the Mountain Land, where the Moodies and Sheba faults, from the northeast, and the Theespruit and Komati River faults, from the east, converge towards the extreme southwestern tip of the Mountain Land. Although not proved as yet, because of lack of data, it is tentatively put forward that these two sets of faults join with each other. They would thus represent very early faults which have been folded. As mentioned previously, a zone of very strong shearing and mylonitization occurs within a narrow belt of homogeneous intrusive granite along the immediate contact zone in the northern part of the Mountain Land. This contact clearly represents a region of strong movement and dislocation, although the amount and direction of movement are not known.

(f) Structural History of the Northwestern Part of the Mountain Land

The gross structural features of the Mountain Land, mentioned above, have to be satisfactorily explained in any theory of the structural history of the area. The small-scale structural features in the northwestern part of the Mountain Land, summarized by Roering (1965), also have to be accommodated in the synthesis.

On the basis of superimposition of structures, a number of distinct periods of deformation have been recognized within this region. The earliest recognizable structures, deformed by all other structures in the area, are the major east-northeast-trending folds and faults which constitute the so-called Main Phase of folding. These structures are over-folded to the northwest, and there is evidence that they were supreimposed on earlier folds about which very little is known. Paralleling this trend along the northern flank of the Mountain Land, is a very strong foliation. The latter is clearly seen in the granite close to the contact, and is manifested in the alignment of metamorphic minerals in the metamorphic aureole of the granite, as well as in a strong cleavage. The latter is best developed in the pelitic sediments of the Fig Tree Series, and in deformed chert pebbles of the Moodies Series. The Main Phase structures, although locally deformed, especially in the vicinity of the granites, are by far the best developed, and give the Mountain Land its grain.

A marked, but local, superimposed phase of deformation occurs in the vicinity of Noordkaap, where the northwest Consort Fold Trend has resulted in the refolding of the Main Phase foliation and cleavage. This is manifest in the arcuation of the Eureka and Ulundi synclines, and the development of the Consort folds and the Jamestown Syncline. The Montrose Fold Trend, south of Barberton, also deforms the Main Phase folds. None of these younger trends can be traced across the Mountain Land, and they are clearly of local origin, being not nearly as pervasive as the Main Phase trend.

A few, very weak phases of deformation post-date all of the above-mentioned deformations. A late-phase, east-northeast fold trend is superimposed on the rotated Main

Phase cleavage of the Ulundi Syncline, and is also manifest in the disharmonic fold to the southwest of Noordkaap. A final imprint of deformation is represented by small-scale accordion folds, with flat-lying axial planes.

(g) A Synthesis of the Structural Evolution of the Barberton Mountain Land

Deformation of the Swaziland System, as determined from minor structural analysis, is post-Moodies in age. If the Moodies Series represents a true, late-tectonic molasse deposit, then the original geosyncline must have been subjected to earlier orogeny. The effects of such an orogeny cannot be detected beneath the imprint of the post-Moodies deformation. Any structural analysis, therefore, can refer only to the second of at least two major periods of folding and faulting. It is consequently not possible to present the complete tectonic story.

All the major structures referred to earlier have been caused by the intrusion of post-Moodies granites. Forces acting from the south-southeast, in a north-northwesterly direction, produced the regional fold trend (east-northeast), the parallelism of the regional thrust faults, and the overturning of the folds to the north. The gneissic terrain of the Nelspruit area probably acted as a resistant, stable buttress against which the layered rocks were compressed. A good indication of the amount of deformation that these rocks have suffered can be obtained from deformed and flattened pebbles of the Moodies Series. Along the northern contact of the Mountain Land, the flattened and elongated ellipsoidal chert pebbles parallel a well-developed cleavage. It is possible, using these deformed pebbles, to calculate the approximate amount of shortening suffered by the conglomerate horizon at 61 per cent, in (Anhaeusser, 1966b) the Eureka Syncline. Assuming an average width of 17 miles for the Mountain Land, a shortening of between 40 and 80 per cent, and uniform compression over the whole area, and not taking into account the effects of the thrust faults, an approximation of the original extent of the unfolded, layered rocks can be set at between 50 and 150 miles.

Soon after the initial deformation, about which little is known, numerous discrete and homogeneous granite bodies intruded the periphery of the Mountain Land. These probably represented high-level, homogenized, mobile fractions of a lower-lying gneissic terrain. Good evidence of this has been obtained in Swaziland (Hunter, 1965), where the homogenized, synorogenic granite of that territory passes gradationally downward into the Ancient Gneiss Complex, exposed in the deeper river valleys. The granites moved up slowly, all at approximately the same time, in the form of rounded or elliptical bodies, varying in size from 25 miles to one mile in diameter, excluding the huge body of synorogenic granite in Swaziland. These diapiric granites forced their way into the basal part of the Onverwacht Series, and produced local thermal, and strong dynamic, metamorphism of the volcanic series. The volcanics became partly or completely draped around the various plutons, to form the tapering arcuate schist belt remnants described earlier. Most of these bodies caused only very local deformation of the Onverwacht rocks, and had hardly any effect on the east-northeast grain of the Mountain Land. Certain of the larger ones, however, generated a more widespread superimposed deformation. The best example is the Kaap Valley Granite, which was responsible for the Consort folds and the arcuations of the Eureka and Ulundi synclines. In addition, it produced the large-scale structure of the Jamestown Syncline, with its northwest trend at right-angles to the general grain of the Mountain Land. Some, well-developed, anticlinal structures were also produced by certain of these rising, homogeneous domes. The best examples of these include the Steynsdorp Anticline and the Stentor Anticline (Viljoen and Viljoen - in preparation).

Sustained pressure from the southeast resulted in the imprint of a younger, distinct, but weakly developed east-northeast trend parallel to the early Main Phase trend. This same force was probably also responsible for the thrusting of the folded rocks on to the stable buttress of the Nelspruit gneiss and migmatite to the north. This resulted in the strong post-crystallization mechanical deformation observed within the granites along the immediate contact zone in the north.

Finally, a sequence of rather brittle accordion folds and conjugate folds were developed over wide areas in the northwestern part of the Mountain Land. All of these folds indicate a near-vertical stress field. It is possible that the very much younger, porphyritic, homogeneous plutons of the M'pageni-, G.5-, and Dalmein-types were responsible for these folds. These late granites had no part in the major deformations of the Mountain Land, and cut cleanly through all earlier trends and foliations. These granites were, however, responsible for the considerable local faulting of the supra-crustal rocks into which they intruded (Viljoen and Viljoen - in preparation).

G. MINERALIZATION IN THE BARBERTON MOUNTAIN LAND

(a) Introduction

The ancient schist belt of the Barberton Mountain Land has not been merely of scientific interest, for as early as 1883 gold was discovered, and the De Kaap Goldfield came into existence. In the ensuing rush, the Jamestown, Komati, Steynsdorp, and Swaziland fields were opened up, but their lives were short. Several mines in the De Kaap field, however, proved to have major ore-bodies, and have continued production up to the present day. Apart from the gold mineralization, there are several important base metal deposits located within the ancient fold belt. Notable are the occurrences of chrysotile asbestos and iron-ore. In addition, lesser amounts of magnesite, talc, barytes, tin, and ornamental stone (buddstone and verdite) have been mined from the area. Minor occurrences of the nickel mineral, trevorite, have also been found, but have proved to be uneconomic.

(b) Controls of Mineralization

Investigations relating to the economic geology of the Barberton Mountain Land have shown, almost without exception, that mineral deposits owe their origin to some form of structural control. Possible exceptions are some of the talc and magnesite occurrences formed as a result of the local intrusion of quartz and felspar porphyry bodies, and the barytes and iron deposits, both of which owe their origin primarily to stratigraphic control.

(c) Gold Mineralization

The importance of faults in the development and distribution of gold mineralization has long been recognized. In the northern portion of the Mountain Land, most of the gold mineralization has been located close to the Lily, Sheba, Scotsman, and Barbrook faults. On the Swaziland side, the gold mineralization of the Forbes Reef area is located along, or adjacent to, areas of faulting. The major faults are not mineralized continuously along their strike, and indications are that second-order phenomena, associated with the parent structures, were the main controlling factors for the localization and concentration of ore-forming fluids. Evidence of horizontal movements having taken place along the major faults is available, and it has been demonstrated that much of the gold mineralization is intimately associated with the effects of wrench-faulting (Anhaeusser, 1965).

The gold-producing area around Barberton suffered at least five separate phases of deformation (Roering, 1965). Poole (1964) found that the main control in the locali-zation of the ore-bodies in the Agnes Gold Mine was exerted by structures developed during the second phase of regional deformation. Anhaeusser (1965) suggested that the mineralization was introduced over a wider range of time, beginning during the second phase of deformation, and continuing through into the third phase. It was also suggested that the mineralization is of two different types — the earlier gold being intimately associated with sulphides, and the later gold being virtually devoid of sulphides, and occurring essentially as gold-quartz veins.

The New Consort Gold Mine affords an example of mineralization occurring at a "schist-shale" contact. In the mine the "Consort Contact" is a highly sheared contact between competent Fig Tree shales and incompetent talc and amphibole schists of the underlying Onverwacht Series. Viljoen (1964) considered that the localization of the Consort mineralization was due, partly, to the fact that the contact was also a zone of extensive differential movement, and that the younger Consort folds, produced by the intrusion of the Kaap Valley Granite, attain their best development in the mine area. The Fairview and Sheba mines, two of the largest gold producers in the Mountain Land, are further examples of ore-bodies controlled by structure. The mineralization also occurs in, or adjacent to, the Zwartkoppie Stage, at the base of the Fig Tree Series, in contact with basic schists of the Onverwacht Series. Both these mines are situated close to the Sheba Fault, separating the Moodies rocks of the Eureka Syncline from the Fig Tree rocks of the Ulundi Syncline. The fracture patterns in these mines were considered by Anhaeusser (1965) to have been produced by wrench movements formed by the reactivation of pre-existing longitudinal thrust fault planes. The regenerative stresses apparently created suitable second-order structures into which payable ore migrated. It is noteworthy that, in only a few instances, have the major fault planes themselves provided a favourable environment for the accumulation of payable concentrations of gold mineralization. The wrench movements were also responsible, in a number of mines, for the generation of cymoid structures, i.e. fractures splitting from, and rejoining, major shears. It is possible to demonstrate that these structures are frequently responsible for, or act as hosts to, increased gold and sulphide mineralization (Anhaeusser, 1965).

(d) Distribution of Gold Mineralization

The gold mines of the Barberton Mountain Land are, as has been previously stated, mainly situated in close proximity to major regional faults, the subsequent movements along which have resulted in the production of second-order faults and fractures. The majority of the ore-bodies are thus located in an environment dictated by the varying influences and effects of fault deformation. Away from the sphere of influence of the major planes of weakness, the incidence of gold mineralization clearly declines, and is either poorly developed or totally absent.

Coupled with the overall fault control is the effect, on a regional scale, of the various phases of intrusive granite, and the associated contact metamorphic effects on the rocks of the Swaziland System. Here again, it can be demonstrated that the more significant gold mineralization lies in a broad zone adjacent to the periphery of the Mountain Land and that this mineralization decreases progressively away from the influence of the granite contacts, until it becomes virtually non-existent in the heart of the fold belt proper.

(e) Types of Gold Mineralization

De Villiers (1957) made a general study of the mineralogy of the gold ores of the Barberton area, and recognized four main types of ore, viz:-

1. ore containing arsenopyrite and pyrrhotite,
2. pyritic ore,
3. lead-bearing ore,
4. antimonial ore.

To this list Gribnitz et al. (1961) added a fifth type — gold/quartz ore. De Villiers (1957) concluded that all the deposits seemed to have originated at moderate to great depths, but that various temperatures of formation were represented. Hypothermal, mesothermal, and epithermal occurrences are to be found. The ores with arsenopyrite were formed at great depth and high temperature. The pyritic ores also appear to be hypothermal in origin, while the lead-bearing ores belong to the mesothermal class. The antimonial ores seem to have been deposited during the last stages of hypothermal activity, and exhibit characteristics of both mesothermal and hypothermal zones.

Gay (1964) completed a minor- and trace-element study of visible, native gold, obtained from 40 localities over the whole of the Barberton Mountain Land. A regional plot of the fineness values revealed the outlines of a possible pattern. The highest values occur in the vicinities of the Agnes, Sheba, and Consort mines. Gay suggested from this that the possible source of the gold mineralization lay beneath these areas. The Kaap Valley granitic pluton, and not the Nelspruit gneisses and granites, is favoured by him as the possible source of the auriferous solutions. Because most of the deposits investigated seem to be of a hypothermal nature, Gay could not detect a readily apparent zoning of the mineralization.

Anhaeusser (1966c) after studying the Lily gold deposit near Louw's Creek, considered that supergene processes of enrichment of the ore had taken place in the oxidized levels of the mine. He furthermore suggested that the process of supergene enrichment of auriferous deposits may have been a major contributing factor to the numerous surface-enriched gold deposits exploited in the early mining days of the Barberton Goldfield.

(f) <u>Other Mineralization</u>

1. <u>Iron-Ore Deposits</u>

The most important iron-ore deposit in the Mountain Land is situated in north-western Swaziland, two miles from the Transvaal border-post at Oshoek. The iron deposit constitutes the spine of Bomvu Ridge, at the southern end of the Ngwenya Range in the Mbabane District. The ore-body is situated in the Fig Tree Series, and is locally composed of sediments comprising alternating bands of siliceous shales and banded cherts. These are followed by a zone of banded ironstones, with subordinate shales, the upper part of which give rise to the ore-body. This is overlain by cherty, felspathic shales. The deposit of hematite occurs in banded ironstones, the folded nature of which appears to have influenced the varying degrees of secondary enrichment of iron and the emplacement of different types of ore (Bursill et al., 1964). The ore-body has been proved to a depth of over 900 feet below surface, and the average export grade of the ore has thus far been of the order of 64-65 per cent Fe (Swaziland Iron Ore, 1965).

Further iron-ore deposits occur in the Fig Tree successions near Malelane on the Transvaal side of the Mountain Land, but mining of these bodies has ceased. These deposits were also formed as a result of secondary enrichment of banded ironstones. nt

2. Magnesite and Talc Deposits

Magnesite deposits occur in the metamorphosed, ultrabasic assemblages of the Onverwacht Series, in the vicinity of Kaapmuiden and Malelane. The magnesite is confined to a specific horizon, in what appears to be a differentiated assemblage of ultrabasic rocks with a lateral development of many miles (Viljoen and Viljoen, 1967b). The magnesite is considered to have formed in the lowermost, more magnesian-rich, ultrabasic layer at the base of a differentiated body, with the best deposits once again being in areas of structural disturbance. In some of the slightly higher, and more iron-rich, phases of the differentiated successions, there is a preferential development of chrysotile asbestos, which also attains its best development in structurally disturbed areas (Viljoen and Viljoen, 1967b).

Talc has been mined from a number of different deposits, mainly in the northern half of the Mountain Land. The talc deposits all occur in the Onverwacht Series, and were formed mainly as a result of metamorphism and steatization of ultrabasic rocks by the intrusive granites and quartz and felspar porphyries.

The ornamental, semi-precious green-stones, verdite and buddstone, are also found in the serpentinites of the Onverwacht Series, in the same general locality as the talc and magnesite deposits.

3. Chrysotile Asbestos Deposits

Several important chrysotile asbestos deposits occur in the serpentinites of the Onverwacht Series. Notable among these are the Havelock occurrence in Swaziland, and the Msauli deposit in the Steynsdorp Valley. In the Jamestown Schist Belt are the workings of the New Amianthus, Munnik Myburgh, Sunnyside (Star), and Marbestos mines. These deposits are thought to be associated with rocks that have undergone some differentiation to form alternating bands of serpentinitic and pyroxenitic material, and differ from the Havelock and Msauli ore-bodies, which occur in serpentinites considered to have been emplaced along fault zones (Viljoen and Viljoen, 1967b). The Sterkspruit, Stolzburg, and Doyershoek mines, near Badplaas, occur in a fault bounded mass of ultrabasic rocks, also displaying signs of differentiation into serpentinitic and pyroxenitic bands. Near Malelane, the Barberton Chrysotile Mine affords further evidence of a differentiated mass, with asbestos fibre being developed in the eastward plunging Koedoe Syncline.

In all cases, structural deformation, combined with suitable host rocks, have been the contributing factors towards the localization of the asbestos ore-deposits. Faulting, in particular, is believed to have been the main controlling factor for the development of the chrysotile fibre. Van Biljon (1964), after studying numerous asbestos deposits in the Barberton Mountain Land, came to the conclusion that a tensional environment was of prime importance for fibre formation, and that hydrothermal solutions merely assisted the process. The ore deposits associated with folds, viz. New Amianthus, Barberton Chrysotile, and Marbestos mines, were formed in serpentinites that had been subjected to tensional effects in the hinges of synclinal structures.

TOWARDS AN EVOLUTIONARY MODEL OF THE BARBERTON MOUNTAIN LAND

The supra-crustal rocks of the Barberton Mountain Land are identical in sequence and type to those found in younger geosynclines and island arcs. The Onverwacht

Series would be equivalent to an ophiolite assemblage, the Fig Tree Series to a flysch assemblage (or greywacke suite), and the Moodies Series to a molasse-type deposit. The question is whether or not the Barberton rocks were deposited in a geosyncline? The latter is defined as an elongate basin, filled with sediments and volcanics, up to several kilometres in thickness, and which have been strongly folded.

Geosynclines generally show the following characteristics. They are made up of two major troughs, separated by an intervening ridge. Frequently the geosyncline is situated at the continental margin and comprises a series of ridges and furrows. Passing from the continent, or craton, the miogeosynclinal furrow, the miogeosynclinal ridge, the eugeosynclinal furrow, and the eugeosynclinal ridge are successively encountered (Aubouin, 1965; de Sitter, 1964). The two furrow-like depositories are generally filled by material derived from the eugeosynclinal ridge area. The eugeosyncline is characterized by the presence of ophiolites, while the miogeosyncline does not act as host to this rock assemblage. A diagnostic characteristic of a geosyncline, that follows the extrusion of the ophiolites, is an enormous thickness of greywackes and shales — often referred to as the 'greywacke suite', or flysch, and is generally formed by turbidity currents. According to Aubouin (1965) the flysch fills firstly, the eugeosyncline, and then the miogeosyncline. The flysch deposition also has a migratory tendency which is in prelude to orogeny and which has its beginnings in the eugeosynclinal ridge and moves gradually outwards in time, towards the stable craton. The orogeny in the eugeosynclinal ridge and furrow area is also associated with metamorphism and granitization. Large granitic batholiths are the result of these processes, and they tend to be confined to the eugeosynclinal area (King, 1959; Eardly, 1962). Molasse deposition, which contrasts strongly with the deep-water turbidite flysch, marks the end of the metamorphic cycle (Sutton, 1965). These deposits comprise shallow-water sediments in the form of conglomerates, quartzites and shales. Separate molasse basins can occur in various positions within the geosyncline, depending upon which areas were uplifted the most to provide the detritus. The orogeny also gives rise to various fold styles, or types of folds, depending upon the position in the geosyncline.

At least two criteria diagnostic of geosynclines are furnished by the Barberton rocks, viz. the appreciable thickness of the sediments and volcanics (which are, furthermore, geosynclinal in type), and the ubiquitous, tight, isoclinal folding. What are lacking are the elongate nature of the depository and the characteristic major units of a geosyncline, i.e. eugeosyncline, intervening ridge, miogeosyncline, and continent or craton. This is due to granites entirely surrounding and intruding the supra-crustal rocks, obliterating any evidence in support of the depository having been considerably larger. Without the necessary geographic distribution of the required geosynclinal elements in the Barberton Mountain Land, the rocks themselves have to be employed to provide clues as to the environment of deposition. Another complicating factor, in deciphering the characteristics of ancient geosynclines, hinges heavily on the significance of ophiolites. Presumably, in ancient times the crust was considerably thinner and, therefore, the distinction between miogeosyncline and eugeosyncline, based on the presence of ophiolites in the latter, may not be valid. With a thinner crust, ophiolites may have occurred in both the miogeosyncline and the eugeosyncline.

It is quite clear that the rocks must have been deposited in a deep trough of some sort. The reason for this is the enormous thickness (seven miles) of Onverwacht rocks found in the southwestern part of the area. This is a minimum value, as the lower contact has been removed by the intrusion of granite. These volcanic rocks are followed by a substantial thickness (at least two miles) of Fig Tree material, and a similar thickness of Moodies sediments. There is very little unconformity between the Fig Tree Series and the Onverwacht Series which then would indicate a down-sagging, of the order of ten miles, or approximately one-third of the thickness of the present continental crust. It is impossible to obtain an exact thickness of conformable sediments in this area which would indicate the true amount of down-sagging. The only equivalent environment, with respect to down-sagging and infilling of volcanics and sediments of the type outlined above, is the geosyncline, or island arc.

At least one side of the trough may have been fault bounded. The faults must also have been sufficiently deep to allow the flow, from the earth's mantle, of basaltic, ultramafic, and more acid magmas into the trough to form the Onverwacht succession. It is proposed, therefore, that the Onverwacht and Fig Tree rocks must have been deposited in a deep, water-covered (pillow lavas, turbidites), possibly fault-bounded (on at least one side) trough. The faults may also have contributed to the genesis of the flysch-like Fig Tree sediments. Detrital material may have been removed from the fault zones by means of gravity slides.

As outlined so far, the rock succession is very similar to that of other shield areas (greenstone-greywacke assemblages), which are so characteristic of island arcs (Engel, 1966). However, the next stage in the evolution of the Barberton fold belt contrasts with the earlier events. Earth movements must have been active to account for the folding of strata that took place before the deposition of the Moodies sediments. This is manifested by the unconformable nature of the Moodies rocks at certain localities in the Mountain Land. Moreover, the Moodies sediments are of a continental type, in contrast to the turbidites of the Fig Tree. Similar evolutionary patterns are found in younger geosynclines, where molasse deposits follow closely after major events of orogeny, metamorphism, granitization, and regional uplift. Whether or not these events occurred adjacent to the supra-crustal rocks of the Mountain Land will never be known, because the intrusive granites have obliterated most of the other portions of the depository. This hypothetical granitic and orogenic event should not be confused with a similar event which actually took place in post-Moodies times. If such a geosynclinal cycle did not take place, then basement granite must have been exposed adjacent to the trough, in order to account for the granitic detritus found in the Moodies rocks. This would also, probably, indicate earth movements on a significant scale. As already outlined in this paper, three major groups of granitic rocks are present in the area. The oldest are considered to be basement on which the supra-crustal rocks were deposited. These comprise numerous migmatites and granitic gneisses found over vast areas.

After the deposition of the Moodies sediments the next important event was the intrusion of the 3,000 m.y.-granites. This second group includes the homogenized portions of the Nelspruit and Badplaas Granites, the Kaap Valley Granite, and the Synorogenic and Late-Orogenic Granites of Swaziland. At $\pm$ 3,000 million years ago (Allsopp et al., 1962), much of the earlier basement granite was probably rendered palingenic and rheomorphic. The granites of the second group are probably anorogenic (Roering, 1967), and have the following characteristics:

1. they were intruded more-or-less simultaneously (Roering, 1965);

2. they are diapiric in shape, being capped by a zone of homogeneous granite, which gives way downwards to nebulites, and, ultimately to gneisses and migmatites; the latter probably represent the original granitic basement (Hunter, 1965);

3. the granites are distinctly intrusive, and give rise to a contact metamorphic aureole against the supra-crustal rocks; this contrasts with anatectic granite generation, where extensive zones of gneisses and metamorphites surround the more homogenized granite masses (Raguin, 1965);

4. the intrusion of granite is responsible for much of the deformation of the supra-crustal rocks of the Barberton Mountain Land.

Granites of this type are thought to have been derived from differentiative processes in the mantle (Roering, 1967; Engel, 1966). Such a process could possibly take place on a continental scale, and, possibly, at these very early times, was directly responsible for the formation, and/or thickening, of the granitic crust.

The third granitic group are represented by the high-level, medium- to coarse-grained porphyritic post-orogenic granites of Swaziland, and of the M'pageni, Salisbury Kop, and Dalmein plutons. These may have had a similar origin to the 3,000 m.y.-granites, but are preserved at a very much higher structural level than the latter.

The dykes are the youngest manifestation of the schist belt. They were intruded after the granitic events, and were formed on a craton. Epeirogenic movements possibly accounted for macro-joints and faults which were subsequently filled with essentially basaltic magma.

From the discussion above it is clear that there were two important events in the evolution of the Barberton Mountain Land. These events may well be applicable to other ancient fold belts. There is firstly, the geosynclinal event, with a period of trough development, the extrusion of an ophiolite suite with its associated sediments, the deposition of a flysch or greywacke suite of sediments, a period of orogenesis associated with the metamorphic and granitic phenomena and, lastly, the deposition of a molasse facies, derived from areas which were exposed during orogenesis and mountain building. Second, is the granite event which may be repeated at different intervals of geologic time.

The relationship between the geosynclinal cycle and a particular granite event should be considered first. It has been shown in this paper and elsewhere, that the 3,000 m.y.-old granites are post-Moodies and, therefore, post-molasse, in age. This group of granites cannot thus, be compared with granitic and metamorphic phenomena associated with the classic events in a geosyncline. As Read (1957) has pointed out "the post-orogenic sediments (i.e. the molasse) are clearly the wrong setting for granitization they are too distant in time and place from the source of granite". Furthermore, it is generally accepted that the onset of molasse deposition marks the end of the orogenesis, metamorphism, and associated granitic phenomena (Sutton, 1965). It would, therefore, appear that the 3,000 m.y.-granite event is independent of the sequence of events in a geosyncline.

The two fundamental elements or episodes which thus emerge from the Barberton area are, the geosynclinal event, and the granite event. The area can be considered as comprising two distinct and apparently unrelated models. These two models are diagrammatically depicted in Figure 4, where the evolution of both is plotted against the relative intensity of earth movements. It can be assumed that some very early earth movements, probably in the form of warping and/or faulting, gave rise to the embryonic down-sag or trough close to, or on the site of, the present Mountain Land. The ophiolites of the Onverwacht Series poured out into a slowly sagging trough, but no signs of any significant earth movements are found. The style of sedimentation and the type of sediment in the Fig Tree Series clearly indicates fairly strong and increasing earth movements, as depicted by turbidite slumps. If we assume that the Barberton area has followed the course of evolution of any typical geosyncline, then the peak of the earth movements would have been reached by orogeny and associated phenomenon. However, no evidence of this geosynclinal orogenic event has yet been found in the Barberton area because of the obliteration of all surrounding areas by the younger 3,000 m.y.-old granite event. The Moodies Series was then deposited in a declining regime of earth movements as a molasse-type deposit, derived from the postulated folded and uplifted orogen.

A time break of unknown duration then followed, until, with strong earth movements, the 3,000 m.y.-old granites were forcefully emplaced. These effectively obliterated almost all of the early history of the geosynclinal model, and were responsible for much of the presently observable, and decipherable, contact metamorphism, strong folding, and faulting. After crystallization of these granites the Mountain Land and environs, attained very nearly their present-day disposition. Into this stable craton were then intruded the younger granites, which had no significant effect on the structure of the Mountain Land, and, finally at a later date, the various dykes were injected.

Figure 4 depicts a very broad framework of the evolution of the geosynclinal cycle. As was outlined previously, and as can be seen in Figure 5, these major divisions can be further broken-down into smaller units. These units tend to be cyclic in nature. In the Onverwacht Series this cyclicity is very well displayed in the lower and upper stages. In both, basic lavas are followed upwards by salic tuffs and/or agglomerates, and individual cycles are often capped by cherts. In the Middle Onverwacht no acid material, or siliceous sediments, are present, but here there appears to be a cyclic sequence of ultrabasic material and basic lavas. The origin and significance of the igneous cycles is not fully understood but it seems probable that they may be a result of processes within the upper mantle. There is very frequently a close association between the outflowing of acid lava and/or tuff, and the formation of cherts. It seems as though the latter have formed by some exhalative process, and that the silica of the cherts has been, in some way, derived from, or closely associated with, this acid material.

In both the Fig Tree and Moodies Series there are sedimentary cycles, each of which shows a size variation from coarse material at the base, to finer material at the top. The cycles are numerous, and often very small, in the case of the Fig Tree Series, and grade generally from greywacke to shale and then chert. In the Moodies Series three larger cycles are present. These grade from coarse conglomerate, through quartzite, shale and finally jaspilite. The cyclic nature of the Fig Tree Series could be due to turbidity currents, followed by periods of quiescence and chemical precipitation. In the Moodies Series, the cycles are probably to be ascribed to uplift in source areas initially providing coarse detritus to form the base of the cycle. With further erosion of the uplifted area, the sediments become finer until finally, chemical precipitates accumulate in the form of jaspilites.

If, as in the case of the Barberton area, the 3,000 m.y.-old granites were not related to the earlier geosynclinal cycle, then there could be far reaching implications. For example, the granite might appear anywhere in the sequence of events of an Archean geosyncline. If it were to occur say, after the deposition of the ophiolites, then presumably, the cycle could not continue because the crust had been thickened by the addition of granite from the mantle, and a new geosynclinal cycle would have to start elsewhere. Ancient geosynclinal remnants may, therefore, vary in the sequence of rock-types present, e.g. they may consist of greenstone belts, greenstone-greywacke belts, or greenstone-greywacke-molasse belts, as at Barberton. It is suggested that the Barberton Mountain Land is unique by virtue of its preservation, quality of exposure and evidence of the complete geosynclinal cycle.

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Key to Figures

Figure 1 : Locality Map showing the position of the Barberton Mountain Land relative to other Archean fold belts in Southern Africa.

Figure 2 : Geological Map of the Barberton Mountain Land.

Figure 3 : Structural Map of the Barberton Mountain Land.

Figure 4 : Diagram illustrating the model of the elements and evolution of an Archean fold belt as determined from an analysis of the Barberton Mountain Land.

Figure 5 : A stratigraphic column showing the elements of the Swaziland System stratigraphy in the Barberton Mountain Land.

* *

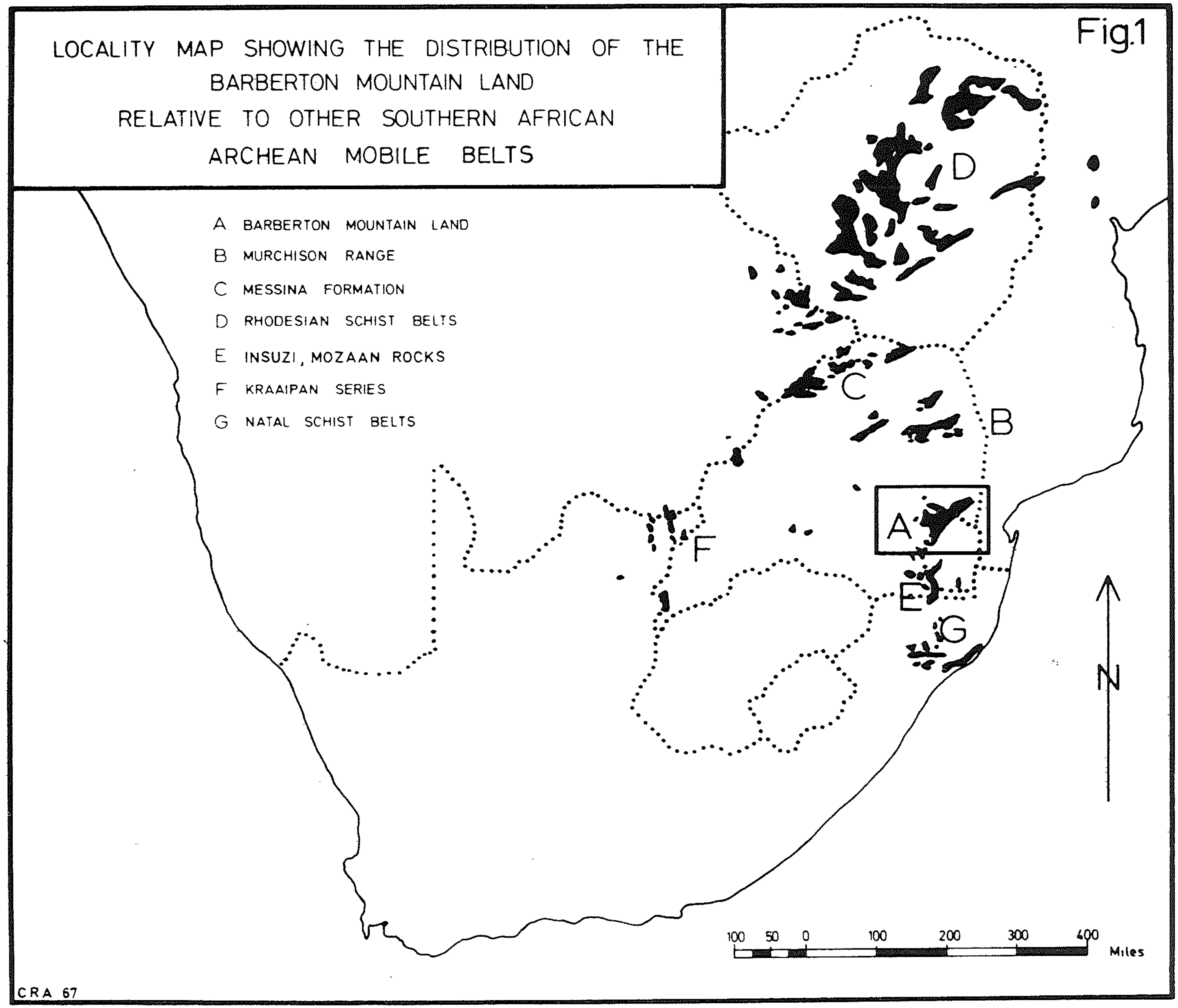


Fig.1
LOCALITY MAP SHOWING THE DISTRIBUTION OF THE BARBERTON MOUNTAIN LAND RELATIVE TO OTHER SOUTHERN AFRICAN ARCHEAN MOBILE BELTS
A BARBERTON MOUNTAIN LAND
B MURCHISON RANGE
C MESSINA FORMATION
D RHODESIAN SCHIST BELTS
E INSUZI, MOZAAN ROCKS
F KRAAIPAN SERIES
G NATAL SCHIST BELTS
A
B
C
D
E
F
G
N
100 50 0 100 200 300 400
Miles
CRA 67

Fig. 2

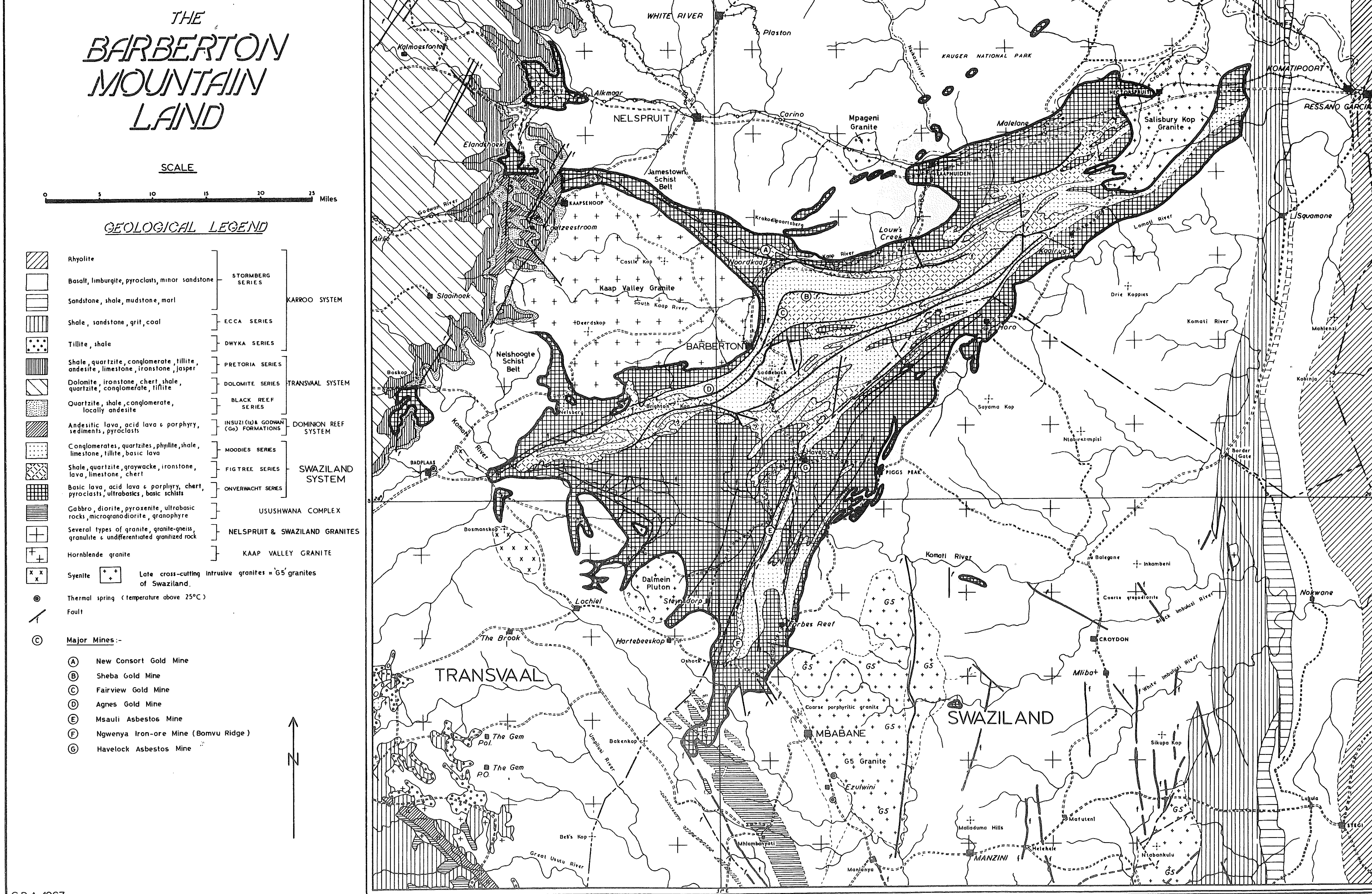
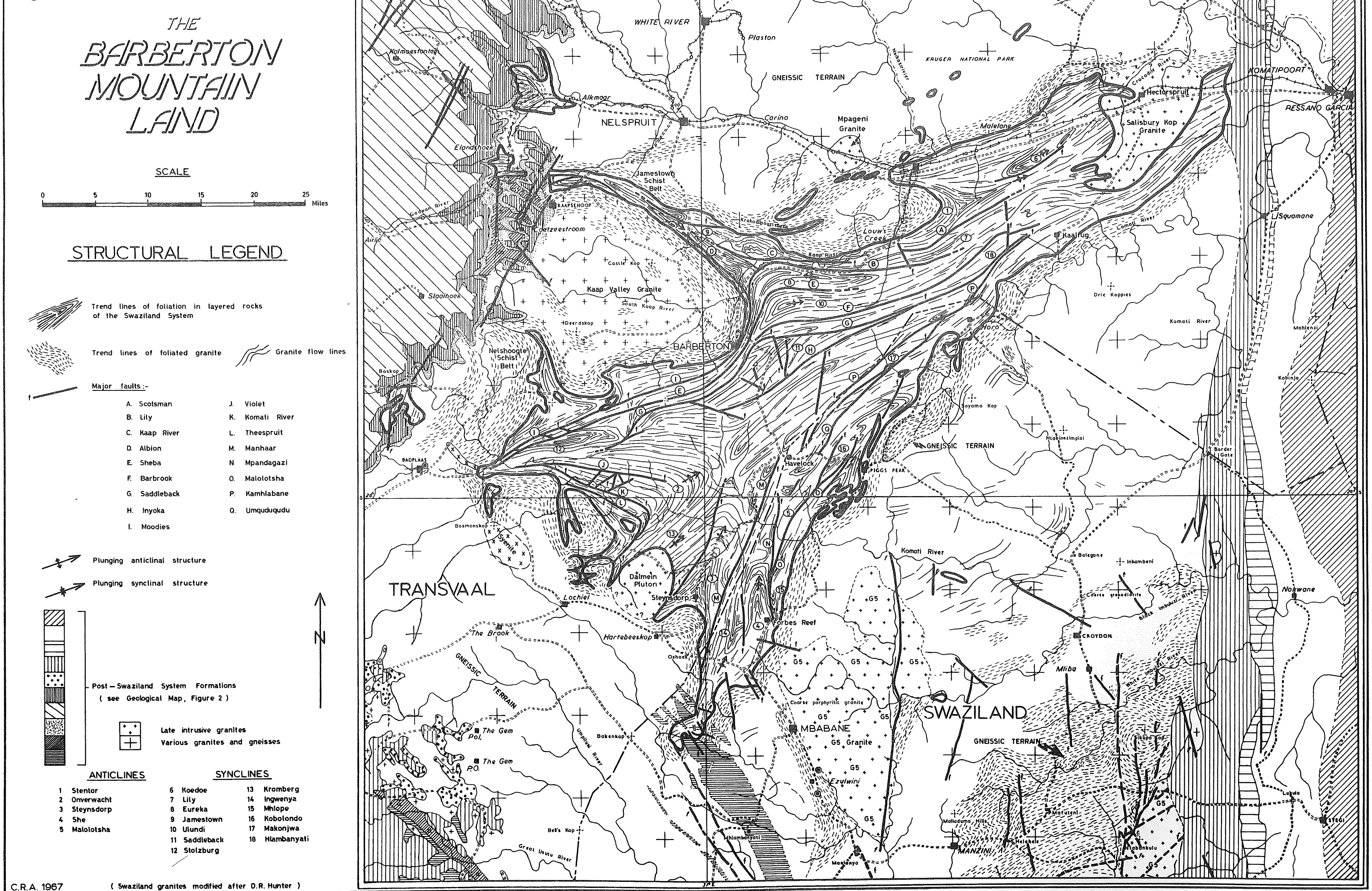

THE BARBERTON MOUNTAIN LAND
SCALE
0 5 10 15 20 25 Miles
GEOLOGICAL LEGEND
Rhyolite
Basalt, limburgite, pyroclasts, minor sandstone
Sandstone, shale, mudstone, marl
STORMBERG SERIES
Shale, sandstone, grit, coal
ECCA SERIES
Tillite, shale
DWYKA SERIES
KARROO SYSTEM
Shale, quartzite, conglomerate, tillite, andesite, limestone, ironstone, jasper
PRETORIA SERIES
Dolomite, ironstone, chert, shale, quartzite, conglomerate, tillite
DOLOMITE SERIES
Quartzite, shale, conglomerate, locally andesite
BLACK REEF SERIES
TRANSVAAL SYSTEM
Andesitic lava, acid lava & porphyry, sediments, pyroclasts
INSUZI (Iz) & GODWAN (Go) FORMATIONS
DOMINION REEF SYSTEM
Conglomerates, quartzites, phyllite, shale, limestone, tillite, basic lava
MOODIES SERIES
Shale, quartzite, graywacke, ironstone, lava, limestone, chert
FIGTREE SERIES
Basic lava, acid lava & porphyry, chert, pyroclasts, ultrabasics, basic schists
ONVERWACHT SERIES
SWAZILAND SYSTEM
Gabbro, diorite, pyroxenite, ultrabasic rocks, microgranodiorite, granophyre
USUSHWANA COMPLEX
Several types of granite, granite-gneiss, granulite & undifferentiated granitized rock
NELSPRUIT & SWAZILAND GRANITES
Hornblende granite
KAAP VALLEY GRANITE
Syenite
Late cross-cutting intrusive granites = 'G5' granites of Swaziland.
Thermal spring (temperature above 25°C)
Fault
Major Mines:-
A New Consort Gold Mine
B Sheba Gold Mine
C Fairview Gold Mine
D Agnes Gold Mine
E Msauli Asbestos Mine
F Ngwenya Iron-ore Mine (Bomvu Ridge)
G Havelock Asbestos Mine
N
WHITE RIVER
Plaston
KRUGER NATIONAL PARK
KOMATIPOORT
RESSANO GARCIA
Kalmoesfontein
Alkmaar
NELSPRUIT
Carino
Mpageni Granite
Malelane
Crocodile River
HECTORSPRUIT
Salisbury Kop Granite
Elandshoek
Jamestown Schist Belt
KAAPMUIDEN
KAAPSEHOOP
Godwan River
Krokodilpoortsberg
Louw's Creek
Squamone
Lomati River
Airlie
Castle Kop
Noordkaap
Kaap River
Koalrug
Kaap Valley Granite
South Kaap River
Slaaihoek
Drie Koppies
Deerdskop
Komati River
Mahlenzi
BARBERTON
Horo
Nelshoogte Schist Belt
Saddleback Hill
Boskop
Kobinja
Brighton Kop
Sayama Kop
Komati River
Ntabarezimpisi
BADPLAAS
Havelock
PIGGS PEAK
Border Gate
Bosmanskop
Komati River
Balegane
Inkambeni
Dalmein Pluton
Steynsdorp
Coarse granodiorite
Black Imbuluzi River
Nokwane
Lochiel
Forbes Reef
The Brook
Hartebeeskop
CROYDON
Oshoek
G5
TRANSVAAL
Mliba
White Imbuluzi River
Coarse porphyritic granite
SWAZILAND
The Gem Pol.
Bakenkop
MBABANE
Sikupa Kop
The Gem P.O.
Umpilusi River
G5 Granite
Ezulwini
Lubula
Malioduma Hills
Matuteni
STEGI
Bel's Kop
Mhlambanyati
MANZINI
Nhlehele
Ntabankulu
Great Usutu River
Manlanya
C.R.A. 1967

Fig.3


THE
BARBERTON
MOUNTAIN
LAND
SCALE
0 5 10 15 20 25 Miles
STRUCTURAL LEGEND
Trend lines of foliation in layered rocks of the Swaziland System
Trend lines of foliated granite
Granite flow lines
Major faults :-
A. Scotsman
B. Lily
C. Kaap River
D. Albion
E. Sheba
F. Barbrook
G. Saddleback
H. Inyoka
I. Moodies
J. Violet
K. Komati River
L. Theespruit
M. Manhaar
N. Mpandagazi
O. Malolotsha
P. Kamhlabane
Q. Umquduqudu
Plunging anticlinal structure
Plunging synclinal structure
Post – Swaziland System Formations
(see Geological Map, Figure 2)
Late intrusive granites
Various granites and gneisses
ANTICLINES
1 Stentor
2 Onverwacht
3 Steynsdorp
4 She
5 Malolotsha
SYNCLINES
6 Koedoe
7 Lily
8 Eureka
9 Jamestown
10 Ulundi
11 Saddleback
12 Stolzburg
13 Kromberg
14 Ingwenya
15 Mhlope
16 Kobolondo
17 Makonjwa
18 Hlambanyati
C.R.A. 1967
(Swaziland granites modified after D.R. Hunter)
WHITE RIVER
Plaston
KRUGER NATIONAL PARK
GNEISSIC TERRAIN
KOMATIPOORT
RESSANO GARCIA
Hectorspruit
Salisbury Kop Granite
Kalmaestontein
Alkmaar
NELSPRUIT
Carino
Mpageni Granite
Malelane
Elandshoek
Jamestown Schist Belt
KAAPSEHOOP
Coetzeestroom
Louw's Creek
Kaap River
Kaalrug
Squamane
Komati River
Castle Kop
Kaap Valley Granite
South Kaap River
Slaaihoek
Drie Koppies
Deerdskop
Nelshoogte Schist Belt
BARBERTON
Horo
Boskop
Mahlenzi
Kobinjo
BADPLAAS
Havelock
PIGGS PEAK
GNEISSIC TERRAIN
Border Gate
Bosmanskop
Syenite
Komati River
Dalmein Pluton
Steynsdorp
TRANSVAAL
Lochiel
Forbes Reef
Balegane
Inkambeni
Nokwane
Coarse granodiorite
Black Imbuluzi River
The Brook
Hartebeeskop
Oshoek
CROYDON
GNEISSIC TERRAIN
G5
Mliba
White Imbuluzi River
Coarse porphyritic granite
SWAZILAND
The Gem Pol.
The Gem P.O.
Umpilusi River
Bokenkop
MBABANE
G5 Granite
GNEISSIC TERRAIN
Ezulwini
Lubulu
Matuteni
Stegi
Bell's Kop
Great Usutu River
Hlambanyati
Mantenga
MANZINI
Malladuma Hills
Helehele
Kabankulu

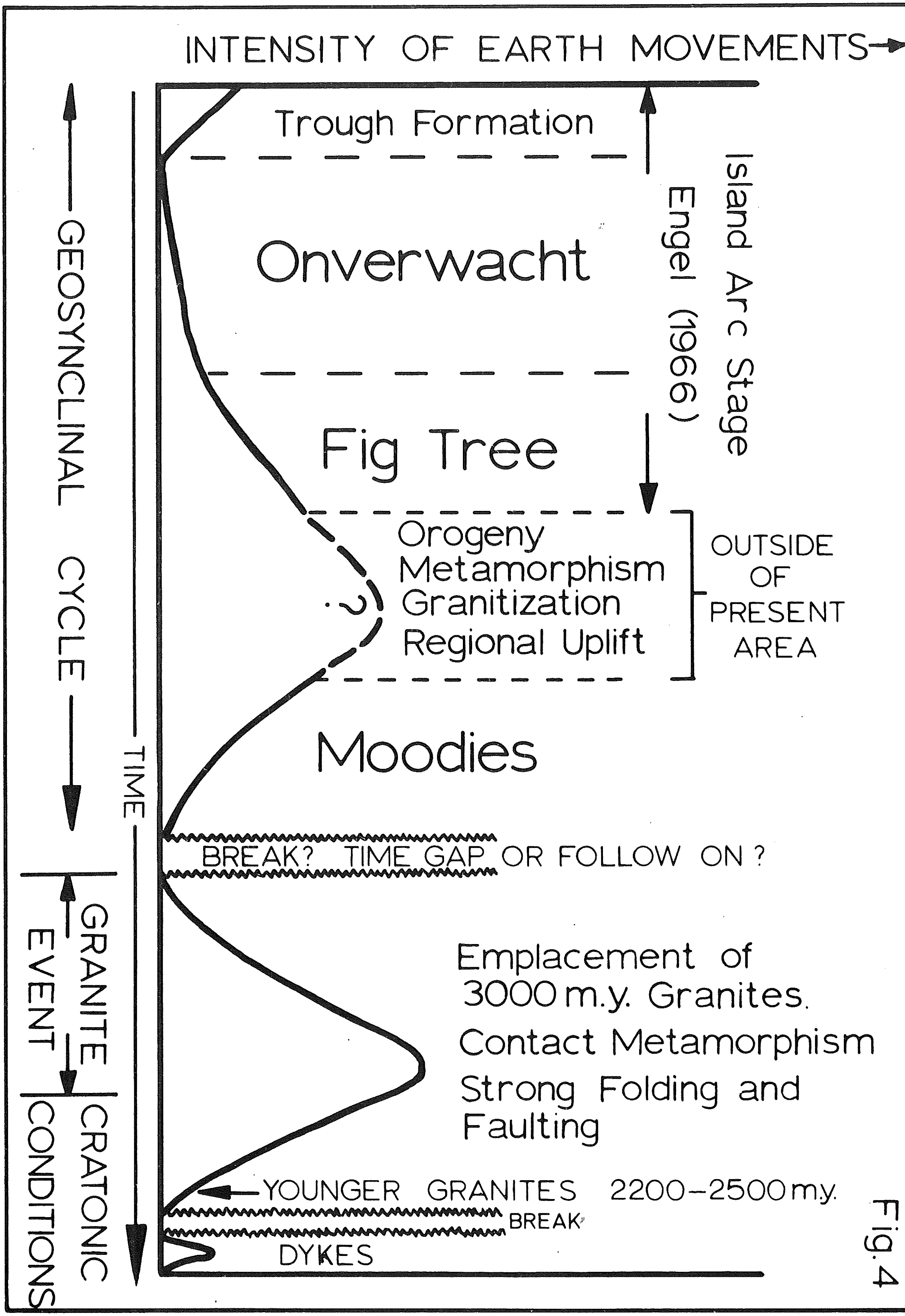

INTENSITY OF EARTH MOVEMENTS
Trough Formation
Onverwacht
Fig Tree
Island Arc Stage
Engel (1966)
Orogeny
Metamorphism
Granitization
Regional Uplift
OUTSIDE OF PRESENT AREA
Moodies
GEOSYNCLINAL CYCLE
TIME
BREAK? TIME GAP OR FOLLOW ON ?
GRANITE EVENT
Emplacement of 3000 m.y. Granites.
Contact Metamorphism
Strong Folding and Faulting
YOUNGER GRANITES 2200-2500 m.y.
BREAK
DYKES
CRATONIC CONDITIONS
Fig. 4

Fig.5

ELEMENTS OF SWAZILAND SYSTEM STRATIGRAPY