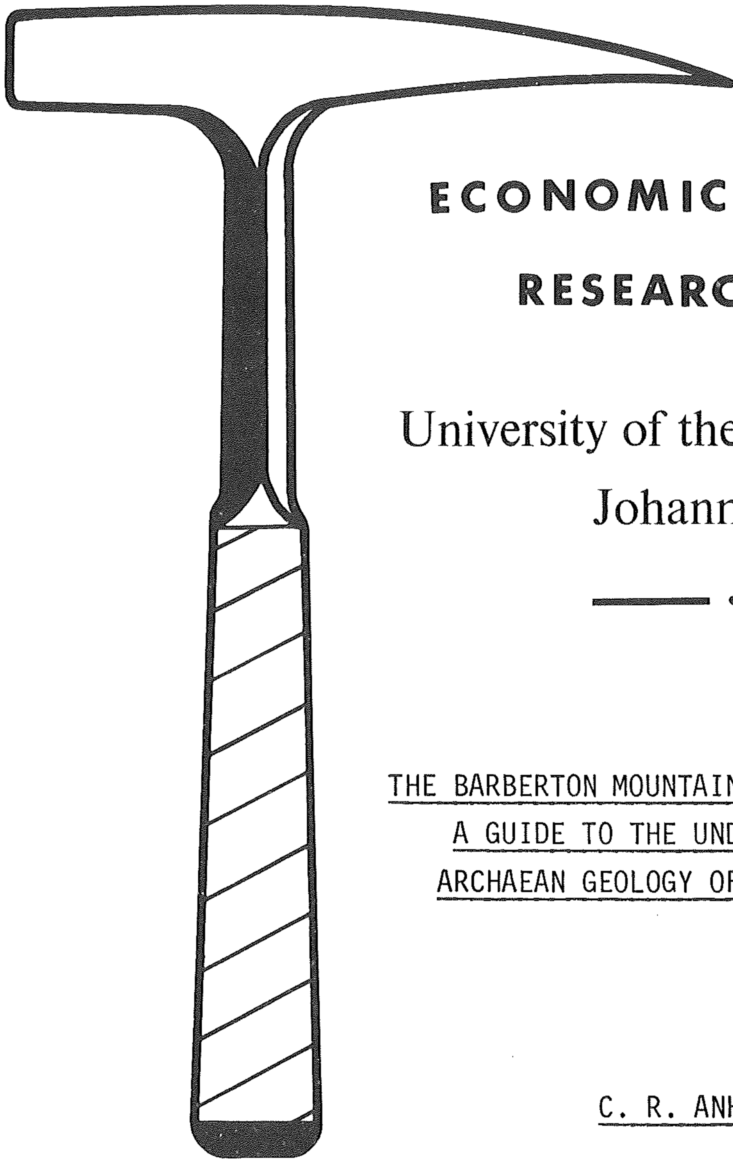

ECONOMIC GEOLOGY RESEARCH UNIT

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THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA - A GUIDE TO THE UNDERSTANDING OF THE ARCHAEAN GEOLOGY OF WESTERN AUSTRALIA

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INFORMATION CIRCULAR No. 55

UNIVERSITY OF THE WITWATERSRAND

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by

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INFORMATION CIRCULAR No. 55

August, 1970

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(for Restricted Distribution)

The information contained herein has been submitted for publication and represents a contribution to the Archaean Rocks Symposium arranged by the Geological Society of Australia and held in Perth, Western Australia, during May, 1970.

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ABSTRACT

The Barberton Mountain Land in South Africa comprises probably one of the most complete examples of an Archaean greenstone belt (± 3,400 m.yrs.) anywhere in the world. A model depicting its geological evolution makes recognition of a lower ultramafic-to-mafic volcanic and igneous assemblage (the Ultramafic Group) and an upper mafic-to-felsic volcanic and pyroclastic succession (the Greenstone Group). The volcanic phase is followed by a terminal sedimentary phase (the Sedimentary Group), the latter being sub-divided into an early, argillaceous succession and a later, arenaceous succession. The granites surrounding the greenstone belt consist of three main types, each with its own distinctive chemistry, mode of emplacement, outcrop style, and deformational characteristics. Other features of the model concern the disposition of the various types of mineralization with respect to host-rocks, mobilizing agencies, and structure, and an endeavour has been made to relate major and minor structural phenomena to events in the evolutionary history of the greenstone belt.

Finally, the various concepts, formulated from the Barberton studies, are applied to some of the Archaean granite-greenstone occurrences of the Pilbara and Yilgarn divisions of the Western Australian shield.

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CONTENTS

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THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA - A GUIDE TO THE UNDERSTANDING OF THE ARCHAEAN GEOLOGY OF WESTERN AUSTRALIA

INTRODUCTION

A considerable amount of renewed interest has lately been shown in the oldest recognizable volcanic and sedimentary remnants of the shield areas of the world. Once the hunting ground of gold seekers, the revival of interest in the Archaean rocks has mainly been brought about following important discoveries, within them, of economically exploitable copper/nickel deposits such as those located in Western Australia, Southern Africa, and Canada. The seemingly complex nature of these ancient remnants has discouraged many investigators from becoming involved with Archaean geology and it is only in the recent past that some concerted efforts have been made to remedy the gaps in the geological knowledge relating to the earth's early history. A few attempts have been made to place the Archaean in broad perspective and to instill some order or method to the approaches of future investigators in these terrains. In Canada, Wilson (1965), and Goodwin (1968a, b) have synthesized the detailed studies made by numerous investigators on the Canadian Shield, while Macgregor (1951) provided some stimulating ideas following examination of the granite-greenstone areas of Rhodesia. In South Africa, syntheses have similarly been undertaken by Anhaeusser and others (1968; 1969). A great deal of new information is also currently available relating to the Archaean geology of Western Australia and it may soon be opportune to consider a similar appraisal of the information thus far assembled in this region.

Having recently undertaken a study tour through both the Pilbara and Yilgarn regions of Western Australia the writer was struck by the poor state of preservation of the rocks and by the general lack of continuity of exposure in many of the areas visited. The awareness of the tremendous problems besetting the investigators of these regions prompted this paper in the hope that it might be of some assistance in resolving many of the difficulties encountered by workers in Western Australia in particular.

GENERAL GEOLOGY OF THE BARBERTON MOUNTAIN LAND

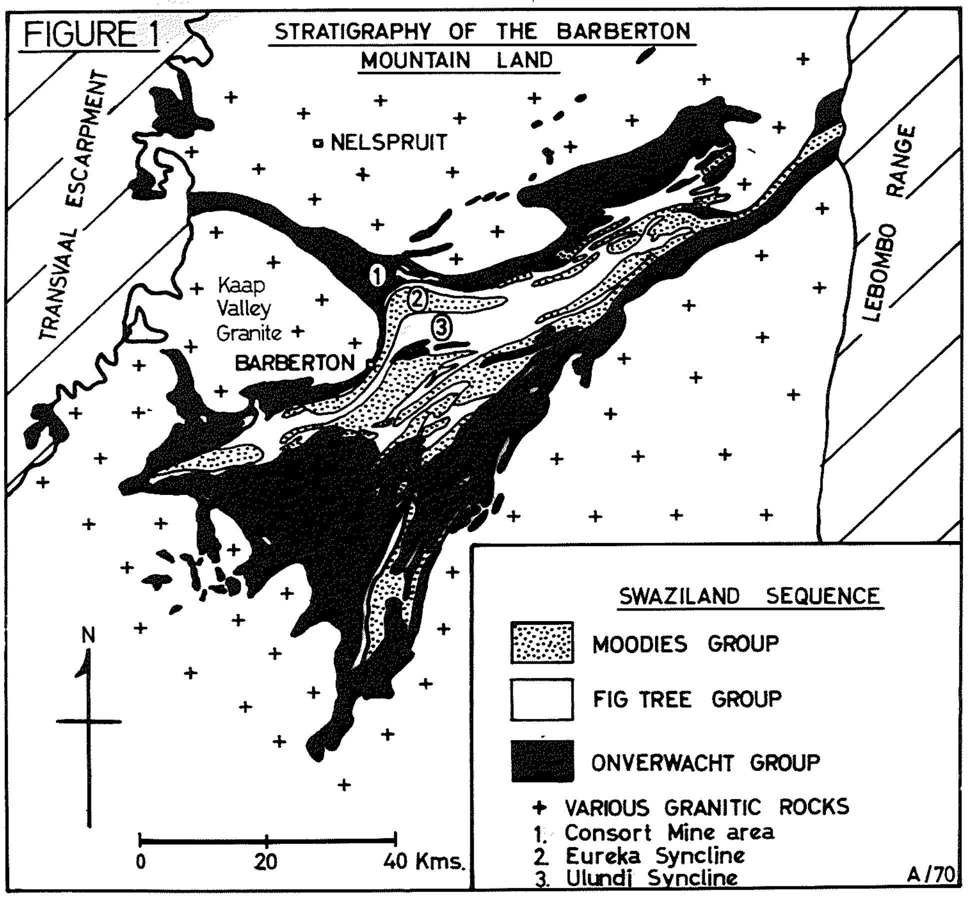
A. Age and Geotectonic Setting

The Barberton Mountain Land, comprising an exceptionally well-developed and well-preserved remnant of an early Precambrian (Archaean) greenstone belt, is situated on the Kaapvaal Craton, which in turn, forms part of the African sub-continental shield area. The cratonic areas on the sub-continent, namely, the Rhodesian Craton and the Kaapvaal Craton are themselves surrounded by younger, linear, high-grade metamorphic mobile belts, such as the Limpopo Belt, the Zambezi belt, the Mozambique belt and others (Anhaeusser and others, 1969).

The Barberton greenstone belt, which has an age of about 3,400 million years (van Niekerk and others, 1967; Allsopp and others, 1968; 1970), represents one of a number of similar Archaean remnants that are widely developed in the ancient granite-gneiss areas of Rhodesia and South Africa. Constituting, as it does, one of the oldest clearly recognizable assemblages of rocks on earth, its exceptional degree of preservation may largely be ascribed to the fact that the region was covered, until comparatively recent times, by a protective cover of younger Precambrian (Proterozoic) strata, now removed by erosion.

B. Physiography and Regional Setting

The Barberton Mountain Land, as its name suggests, is essentially a rugged, mountainous, tract of country lying immediately to the east of the younger cover of the Transvaal Escarpment (Figure 1) and occupies a wedge-shaped, triangular belt extending northeastwards for about eighty miles (130 km) from its broad base in the southwest, to its point of disappearance beneath the Lebombo Mountains (Triassic to Lower Jurassic) on the Mozambique border. The belt tapers gradually from a maximum width of 32 miles in the south, to five miles in the extreme northeast, the average width being approximately 17 miles. The central regions attain the greatest elevations, the highest point being 6,238 feet above sea level. The elevated regions are generally comprised of sedimentary rocks while the less resistant volcanic assemblages occupy the lower lying areas. The entire region, including the granite country, is dissected by numerous deeply incised streams and several major rivers.



C. Geology

Geologically the Barberton Greenstone belt comprises a wide variety of volcanic and sedimentary rock-types that have collectively been grouped into the Swaziland Sequence. The Onverwacht Group at the base attains a thickness of approximately 52,000 feet and has been sub-divided by Viljoen and Viljoen (1970a) into the six formations listed below, each with its own distinctive assemblages and associations of rock-types.

(i) the Sandspruit Formation, at the base, consisting of 7,000 feet of predominantly ultramafic rocks (60-70 per cent) with the remainder comprising mafic rocks and very minor and primitive sedimentary horizons,

(ii) the Theespruit Formation, comprising approximately 6,200 feet of mafic and ultramafic volcanic rocks, together with water-worked felsic tuffs, and some talc-chlorite-carbonate schists and other minor ultramafic horizons,

(iii) the Komati Formation, consisting predominantly of mafic volcanic rocks (70 per cent) and ultramafic rocks (30 per cent). Siliceous members are entirely lacking from this formation, but intrusive quartz and felspar porphyries are present. The Komati Formation is approximately 11,500 feet thick,

(iv) the Hooggenoeg Formation, comprised of a succession of mafic-to-felsic volcanic and pyroclastic cycles. Individual cycles are frequently terminated by substantial and persistent chert horizons. The formation attains a total thickness of approximately 16,000 feet,

(v) the Kromberg Formation, comprising 6,300 feet of mafic lava, felsic lava, and chert, but having in addition, a wide variety of pyroclastic volcanics as well as calc-silicate and carbonate rocks, and, finally

(vi) the Zwartkoppie Formation consisting of 3,000 feet of generally sheared, intermediate to felsic volcanics and interlayered chert horizons.

The lower three formations are composed essentially of mafic and ultramafic rocks, while the upper three formations consist of mafic and felsic volcanics together with a wide variety of siliceous and pyroclastic rocks. Ultramafic bands and lenses also occur sporadically throughout the upper formations. In several localities within the lower three formations a number of layered intrusive ultramafic pods and sills are developed which generally consist of a differentiated assemblage of rock-types comprising dunite, peridotite, pyroxenite, gabbro, and anorthositic gabbro/norite.

Conformably overlying the predominantly volcanic successions of the Onverwacht Group is an assemblage of rocks composed mainly of pelitic sediments together with siliceous chemical precipitates. These rocks, comprising the Fig Tree Group, attain a thickness approaching 10,000 feet. Reimer (1967), has suggested a subdivision of the Fig Tree Group into three formations. The Sheba Formation, at the base of the succession, consists of approximately 3,500 feet of greywackes, with some shales and narrow interlayers of chert and ferruginous chert. A substantial chert and banded ferruginous chert horizon constitutes the base of the overlying Belvue Road Formation. The chert zone is overlain by sandy shales, trachytic tuffs, and fine-grained, dark-green shales. Numerous greywacke, minor chert, and banded ironstone interlayers also occur in the succession which is approximately 2,000 feet thick. The uppermost, or Schoongezicht, Formation commences with coarse trachytic and trachy-andesitic tuffs grading upwards into finer-grained varieties of the same composition. These are overlain by coarse agglomerates, associated trachytic lavas and tuffaceous greywackes, and greywacke conglomerates. The thickness of the formation exceeds 1,500 feet in places.

The Moodies Group follows, in places conformably, and in others unconformably, on the underlying Fig Tree assemblages. The succession, which attains a thickness approaching 12,000 feet, is composed predominantly of conglomerates, quartzites, and shales, together with minor volcanic horizons and banded ironstones.

The supracrustal rocks of the Barberton Mountain Land are surrounded by a variety of intrusive granites which are responsible for the structural deformation as well as regional and contact metamorphism. Isotopic age determinations carried out thus far on the granites indicate ages ranging between 2,200 and 3,400 million years. The granitic rocks range in composition from tonalites, granodiorites, adamellites, to granites, and each variety displays a distinctive tectonic style, mode of emplacement, and age.

Structurally, the Barberton Mountain Land comprises a strongly deformed synclinal, boat-shaped remnant, having a predominantly east-northeasterly trend. Strikingly apparent too, are the narrow arcuate, tapering protuberances of generally schistose Onverwacht volcanic successions which trend in all directions away from the main east-northeast trend (see Figure 2). These protuberances, or schist belts, are the direct result of the intrusion of a number of early diapiric granites that prized apart the successions, stoping and assimilating much of the volcanic material in the process, as well as imposing a distinctive structural imprint on the adjacent formations. Conspicuous within the main body of the Barberton greenstone belt are a series of major fold and fault structures. The folds are predominantly tight synclinal structures with steeply dipping limbs, while the faults are generally extensive longitudinal strike faults which divide the folded belt into a series of long, narrow blocks. Studies reveal that the rocks of the region have been affected by a complex structural history involving several periods of superimposed folding. The structural deformation coupled with the various granite intrusions has been responsible for the low-grade regional greenschist facies of metamorphism which predominates throughout the greenstone belt. Localized upgrading of the rocks into the amphibolite facies is due largely to contact metamorphism caused by granite and pegmatite emplacement.

Hypabyssal rocks, mainly in the form of dykes, and more rarely as sills, are prolifically distributed throughout the entire Barberton region, but attain their maximum development in the areas underlain by granitic rocks. The dykes vary widely in age and in mineralogical and chemical composition.

The Barberton Mountain Land has not been merely of scientific interest but has, for a long time, been an important producer of gold. A number of mines that commenced before the turn of the century are still in operation to this day. Apart from the gold mineralization there are several important base metal deposits located within the greenstone belt notable among which are several major occurrences of chrysotile asbestos and iron ore. In addition, lesser amounts of magnesite, talc, barytes, tin, and ornamental stone have been mined in the area.

MAIN FEATURES ARISING OUT OF THE BARBERTON STUDY

Having as a guide the general geology of the Barberton Mountain Land, there now remains the task of itemizing the main features that have emerged from the numerous studies undertaken in the Barberton region. No detailed description or explanations are entered into in support of the conclusions listed but, where necessary, the reader is referred to the relevant, more comprehensive, accounts dealing with the geology of the region. A summary of the main events in the evolutionary development of the Barberton greenstone belt is also provided in Table 1, and a supplementary diagrammatic summary of the main features pertaining to the area is given in Figure 2.

FIG. 2

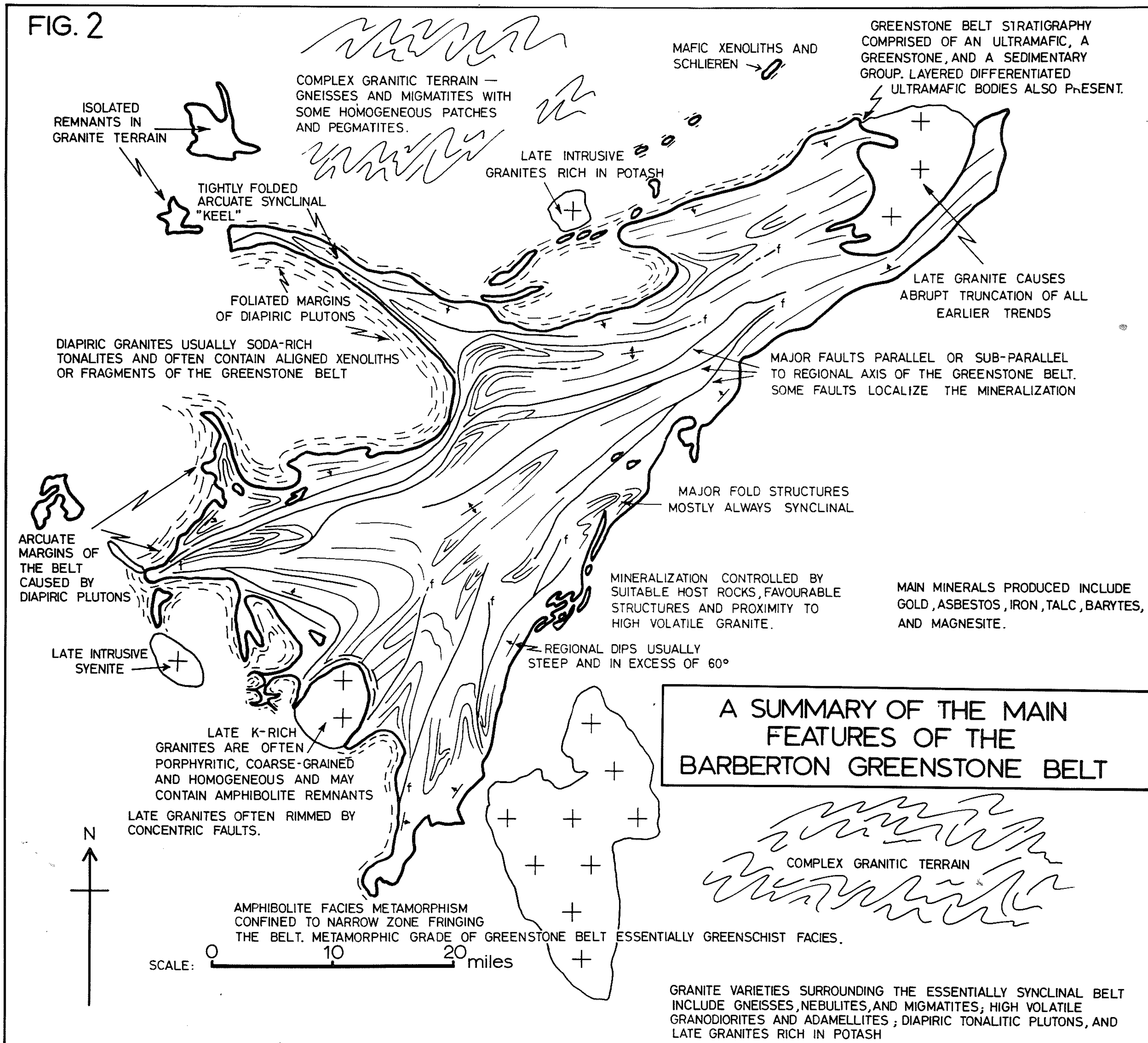


TABLE 1 : SOME OF THE MAIN EVENTS IN THE EVOLUTION OF THE BARBERTON GREENSTONE BELT AND THEIR SIGNIFICANCE

EVENT	SIGNIFICANCE
Barberton greenstone belt covered by Proterozoic sediments (+ 2.0 b.yrs.)	Greenstone belt protected and preserved by cover rocks until recent times.
Intrusion of younger dyke swarms.	Epeirogenic structures invaded by dyke feeders to later formations.
Later intrusion of granodiorite, adamellite, granite, pegmatites (2.20-3.00 b.yrs.)	Metamorphism locally intensified, mineralization of several ages reflects mobilization from successive granite events, late granites truncate earlier structures.
Early tonalitic diapiric granite intrusions (3.00-3.40 b.yrs.)	Stoping and assimilation of greenstone belt, superimposed folding and metamorphism, mobilisation of sulphide mineralization commences. Complex structures developed, migration of mineralization into tensional environments. Serpentinisation of ultramafics, chrysotile asbestos developed.
Depository subsidence continues.	Major regional fold and fault trend intensified, low-grade regional metamorphism superimposed.
Commencement of Sedimentation. Development of rock-types characteristic of the SEDIMENTARY GROUP (Anhaeusser and others, 1969)	
Minor volcanism.	Development of jaspilites, magnetic shales, and banded iron formations.
Basin development, transgression and regression of shoreline.	Cyclic cratonic-type sedimentation in shallow water environment.
Time break - basin subsides, increased uplift of granitic terrain.	Basal conglomerate deposited - unconformities developed in places.
Mild uplift of surrounding granite terrain, continued basin subsidence, minor alkalic volcanism.	Mixing of quartz and K-felspars with material eroded from volcanic rocks. Greywacke conglomerates, tuffs, and agglomerates developed. Nature of volcanism shows progressive changes in residual magma-types, or, contamination.
Cessation of major volcanism. Basin subsidence proceeds, erosion of early volcanic sequences, minor volcanism.	Volcanogenic sediments originate. Cyclic sedimentation controlled by tectonic events or basin subsidence. Minor volcanic and pyroclastic eruptions help trigger off turbidity flows. Energy regime weakens and chemical precipitates deposited. Deep water, euxinic conditions result in the development of black shales.
Continued volcanic and pyroclastic activity. Development of rock-types characteristic of the GREENSTONE GROUP (Anhaeusser and others, 1969)	
Basin subsidence, cyclic volcanism. Extrusion of mafic-to-felsic lavas, and pyroclastic rocks. Chert development.	Magma being tapped from mantle has calcic-to-calc-alkaline affinities and reflects the progressive chemical change of the subcrustal magma with time. Lavas gradually become more viscous, mobility is retarded, and explosive activity intensifies. Volcanic energy regime weakens and siliceous chemical precipitates terminate individual mafic-to-felsic cycles. Cyclic basin subsidence.
Extrusion on minor scale of ultramafic and mafic rock-types. Some differentiation may occur in sills or thick lava flows.	Occasional, irregular, ultramafic and mafic magmas may commence cycles. Limited quantity (< 15 per cent by volume) reflects either, reduced amount available in fractionated supply chambers or, contamination on passage to surface.
Intrusion of Na- and K-rich porphyries, sialic crust thickens.	Apparently related to felsic volcanic rocks and hence may represent some form of fractionated derivative. Increased Na-K suggests a possible genetic link with nearby granodiorites, adamellites, and granites.
Commencement of Volcanism. Development of rock-types characteristic of the ULTRAMAFIC GROUP (Anhaeusser and others, 1969)	
Extrusion of ultramafic and mafic lavas and tuffs.	"Primitive" peridotitic and basaltic komatiites not previously described (Viljoen and Viljoen, 1970). Unusual chemistry - low alkalis, high Ca/Al ratio, high magnesium - demonstrates relatively low degree of contamination of magma on passage to surface through thin crust.
Development in pods, sills, and lenses, of layered differentiated ultramafic igneous bodies.	Fractionated magma in sills possess same bulk chemical composition as penecontemporaneous volcanic rocks.
Siliceous, aluminous, tuffs and Na-rich porphyries make a restricted appearance.	Felsic and siliceous distillate products (acidic residuum) of the ultramafic and mafic assemblages. Porphyries may be genetically linked with the Na-rich tonalitic granites.
Cyclic magma-type trend from "primitive" ultramafic and mafic volcanics to tholeiitic volcanics.	Subcrustal magma undergoes changes including gravitative and pneumatolytic differentiation, fractional crystallization and contamination by progressively thickening sialic crust.
The early crust.	Thin crust, in part granitic ? Unstable conditions result in mantle tapping fracture development and the onset of volcanism.

1. The nature of the early crust underlying the basal volcanic rocks of the Barberton greenstone belt still remains speculative as the lower formations are always intruded by granitic rocks. Some sialic crustal material may have been present at an early stage but, due to its instability, was probably largely destroyed by the subsequent volcanism. Suggestions have been made by Engel (1968) that the early ultramafic and mafic rocks may, in fact, be representative of parts of the early crust during pre-3,400 million year old times.

2. The successions at the base of the Barberton stratigraphic pile have a distinctive chemistry hitherto not recognized. These volcanic rocks have been referred to as basaltic and peridotitic "komatiites" by Viljoen and Viljoen (1970c). Their distribution is restricted primarily to the basal members of the stratigraphic column and they occur associated with minor developments of distinctive high-alumina siliceous rocks, and soda-rich quartz and felspar porphyry bodies. The siliceous rocks are generally quartz-sericite-schist interlayers within the komatiite basalts and peridotites but, may contain in addition, the alumina minerals, pyrophyllite, andalusite, sillimanite, kyanite, staurolite, and chloritoid, depending upon the metamorphic grade. The phyllosilicates sericite, muscovite, and fuchsite, are also commonly encountered (Anhaeusser, 1969; Viljoen and Viljoen, 1970c). The soda-rich porphyries occur as elongate and irregular masses, at times largely conformable with the stratigraphy. Intrusive relationships exist between the porphyries and the surrounding mafic and ultramafic rocks but it appears that they developed penecontemporaneously with these volcanic rocks and may be genetically linked to them (Anhaeusser, 1969; Viljoen and Viljoen, 1970c). The lower three formations of the Onverwacht Group contain an estimated 95 per cent of peridotitic and basaltic rock-types, the balance of 5 per cent consisting of altered felsic tuffs, porphyries, and primitive sedimentary horizons.

3. Many of the ultramafic rocks have been shown to be extrusive peridotitic lava flows (Viljoen and Viljoen, 1970b). However, a number of differentiated ultramafic bodies occur in the lower half of the Onverwacht stratigraphy and appear to take the form of intrusive sills, lenses, and pods. Differentiation of these bodies has resulted in the development of dunites, peridotites, pyroxenites, gabbros, and anorthositic gabbro/norites (Anhaeusser, 1969; Viljoen and Viljoen, 1970d). In most cases the ultramafic rocks have been almost totally serpentinized while the pyroxenitic and gabbroic rocks are altered to amphibolites and meta-gabbros.

A few ultramafic bodies consist of a regular, alternating, layered succession of rocks comprising a number of differentiated cycles. In some cycles the full range of differentiated products may be present, while in others, one or more of the products may be missing. The petrological and chemical evidence indicates that the parental magma which gave rise to these layered successions was not of the normal tholeiitic variety, being instead peridotitic in nature. The bulk chemical composition of two of these differentiated igneous bodies compares favourably with the chemistry of peridotitic komatiite lava flows (Anhaeusser, 1969; Viljoen and Viljoen, 1970d). This suggests that the differentiated ultramafic bodies developed penecontemporaneously with the early peridotitic and basaltic komatiite volcanic rocks. The layered ultramafic bodies are economically important as they are the host rocks to major chrysotile asbestos deposits as well as to occurrences of magnesite, and talc. The semi-precious varieties of serpentinite, known locally as verdite, and buddstone, also occur in these bodies (Anhaeusser, 1969).

4. The volcanic rocks constituting the upper three formations of the Onverwacht Group are entirely different to the lower three formations and are separated from them by a persistent sedimentary horizon referred to by Viljoen and Viljoen (1970e) as the Middle Marker. The marker, which ranges from a mere parting up to 30 feet in thickness, consists of variously coloured banded cherts, banded chert-carbonate zones, tuffs, and carbonaceous chert and shale bands. Sulphides, comprising mainly pyrite, are often conspicuous in the carbonaceous zones. The most striking feature of the uppermost formations is the cyclic nature of the mafic-to-felsic volcanicity, the latter also showing calcic to calc-alkaline chemical affinities. A number of cycles, each commencing with a large accumulation of tholeiitic basalt, pass upwards into andesites, dacites, rhyo-dacites, and rhyolites. The more felsic lavas are generally capped by chert horizons which terminate individual cycles. The mafic component of the cycle becomes thinner with increasing height in the stratigraphic column and, at the same time, there is a progressive increase in the development of felsic volcanic and pyroclastic material. A number of ultramafic dyke-and sill-like bodies occur at various intervals in the upper formations but only constitute a relatively small percentage of the total volcanic assemblage (<15 per cent). Magmatic segregation, giving rise to dunites and peridotites towards the base and a variety of pyroxenites nearer the top, is often apparent in these bodies (Viljoen and Viljoen, 1970e). The

ultramafic horizons are frequently associated with felsic volcanics and chert zones and their position with respect to these latter rock-types suggests that some of them may represent broad lava flows marking the commencement of a volcanic cycle.

Porphyry bodies again make an appearance in the upper formations of the Onverwacht Group but differ from those occurring lower in the stratigraphic column mainly by the variations shown in the alkali content of the intrusives. Whereas the porphyries associated with the lower ultramafic and mafic formations show high Na/K ratios (Anhaeusser, 1969; Viljoen and Viljoen, 1970c), the porphyries associated with the uppermost mafic-to-felsic volcanic assemblages show a considerable potash increase (Viljoen and Viljoen, 1970e). In the same way that the soda-rich porphyries, described earlier, may be genetically linked with the early soda-rich tonalitic granites, so too, may the porphyries displaying increased potash content be genetically linked to the later, more potash-rich granites.

All the rock-types in the region, whether they be granitic, or volcanic, demonstrate a progressive build-up, with time, of their alkali contents. The increase in alkalies, and potash in particular, may be related to the evolutionary development of a progressively thickening sialic crust (Engel, 1968).

5. The cyclical repetition of the volcanism is a particularly important aspect that has emerged from the studies carried out in the Barberton area. The cyclicity is not restricted to the volcanic members of the stratigraphy alone, but is also evident in some of the layered, differentiated, igneous bodies, and in the younger sedimentary successions (Anhaeusser and others, 1968; Anhaeusser, 1969 and 1970).

The volcanic cyclicity can be detected in a variety of ways, with the chemistry of the rocks being particularly definitive. However, where this is not always available, changes in the rock densities and colour index variations, are of assistance in determining the facing direction (way up) of the successions. Dark-coloured rocks (melanocratic) are almost invariably developed towards the base of the pile or cycle (ultramafic and mafic rocks). Progressively lighter colours (mesocratic) indicate a change through the mafic-to-felsic range of rock-types and the very light-coloured rocks (leucocratic) represent the later, more siliceous members. Metamorphism, although it may change the chemistry of the rocks as well as their primary colouration, does not appear to adversely affect the usefulness of the colour index technique of rock-identification. Even in areas where the Archaean rocks are badly altered, sheared, or schistose, the use of the colour index as a guide to mapping, has proved successful.

The cyclicity in the sedimentary successions of the Barberton Mountain Land is demonstrated, not so much by chemical changes, but by textural variations (Anhaeusser, 1970).

6. Immediately following the volcanic rocks that characterize the Onverwacht Group is an assemblage of sediments referred to locally as the Fig Tree Group. The nature and origin of these sediments is of importance when attempting to establish the environmental conditions maintaining during their deposition. The rocks comprising the succession were mainly derived from the erosion of earlier volcanic assemblages. Petrologically the greywacke-shale assemblages show a variety of essentially mafic minerals (Visser and others, 1956; van Vuuren, 1964; Reimer, 1967; Anhaeusser, 1969). Furthermore, trace element studies by Danchin (1967) showed that the shales contain exceptionally high contents of chromium (525-1145 ppm), and nickel (280-800 ppm), suggesting that the ancient rocks from which these sediments are derived were ultramafic in composition. In places, relatively high percentages of quartz, potash felspar, plagioclase, zircon, and apatite are found in these rocks, suggesting that some granitic source was being eroded simultaneously with the early volcanic rocks (Roering, 1967; Reimer, 1967; Anhaeusser, 1969).

Cyclic sedimentation developed in the Fig Tree Group reflects conditions of instability in the basin of deposition. Coarse-to-fine textured sediments occur in the rhythmically bedded units comprising the greywacke-shale assemblage. Chemical precipitates (cherts, banded ironstones, jaspilites) reflect periods of quiescence in the sedimentational cycle. Minor, essentially alkaline, volcanic and pyroclastic rocks occur interbedded with the sediments and probably resulted from tectonic activity associated with the continued subsidence of the depository. A number of sedimentary structures diagnostic of a turbidite succession have been reported (Kuenen, 1963; van Vuuren, 1964; Reimer, 1967). These include slump-bedding, current-marks, load-casts, flute-casts, convolute-bedding, and graded-bedding. Turbidite flows originated as a direct result of basin instability and were also responsible for the local development of shale-pebble conglomerates. Black carbonaceous shales and greenish-black shales demonstrate deep water sedimentation in a highly reducing environment. Iron sulphides (pyrite) are frequently found in these black shale facies (euxinic) rocks.

7. The Fig Tree Group comprises an essentially argillaceous assemblage of rock-types whereas the uppermost, or Moodies, sedimentary succession, consists mainly of arenaceous sediments. Rock-types typical of the group include conglomerates, quartzites, calcareous and felspathic quartzites, sandstones, sub-greywackes, and shales. Minor amygdaloidal volcanic horizons and banded magnetic shales and jaspilites are also present. The close association of the jaspilites and banded iron formations with the volcanic horizons suggests a close genetic link between the volcanism and iron formation. The Moodies successions occur, in places conformably, and in others unconformably, on the underlying Fig Tree assemblage. A basal conglomerate initiates the first of four cycles of sedimentation (Anhaeusser, 1969 and 1970). The rock associations differ from those of the underlying formations in that they show many of the features of cratonic-type sedimentation (L.L. Sloss, personal communication, 1970). The basal conglomerate may have been deposited only after a considerable time lag following the Fig Tree deposition (Anhaeusser and others, 1968). Thereafter, the cyclicity of the sedimentation and the type of sediment laid down suggests repeated transgressions and regressions of the shore-line of the depository. The cuase of each cycle was probably related to tectonic readjustments of the slowly downsagging basin of sedimentation.

The sediments deposited were derived from the underlying greenstone belt formations as well as from a granitic source. Pebble-types include chert, granite, quartzite, jaspilite, quartz and felspar porphyry, greywacke, and even conglomerate pebbles (Visser and others, 1956; Anhaeusser, 1969). The quartzo-felspathic sandstones and quartzites have abundant potash-felspar (microcline, perthite) oligoclase-albite, muscovite, sericite, and quartz, all minerals suggesting erosion from an essentially granitic source.

8. The Onverwacht volcanic assemblages have been extensively altered, in all but a few places, by dynamothermal as well as contact metamorphism and are represented by a wide range of metamorphic rock-types. The metamorphic zoning includes an amphibolite facies immediately adjacent to granites and pegmatites, grading away from the contacts into various sub-facies of the greenschist facies (Urie and Jones, 1965; Anhaeusser, 1969). The Fig Tree and Moodies assemblages rarely display evidence of metamorphic alteration and the original characteristics of the rocks, such as their composition, texture, and sedimentational structures are still well-preserved. Despite the variations in rock-types caused by the metamorphism and structural disturbance, the stratigraphic successions in any part of the greenstone belt can readily be classified into one or more of the three subdivisions defined by Anhaeusser and others (1969). From base to top of the stratigraphic pile an Ultramafic Group, consisting of lavas and intrusives of mafic and ultramafic composition, with minor interbedded sedimentary rocks, chiefly of chemical origin, represents the initial phase of volcanic activity. This is followed by the Greenstone Group, consisting of mafic and intermediate to acid rocks together with interbedded clastic volcanogenic and chemical sedimentary rocks, representing a progression from mafic-to-felsic volcanic rocks. Finally, and unconformably overlying the preceding volcanic phases are rocks of the Sedimentary Group, developed during the closing stages in the evolution of the depository.

9. The successions that comprise the Barberton greenstone belt, have been subjected to considerable structural disturbance following the evolution of the depository on a relatively thin and unstable crust. The first events sited the depository along a fundamental northeast-southwest-trending axis. In this respect, the greenstone belt as a whole, maintains a directional orientation similar to that of a number of other Archaean greenstone belt remnants developed on the Southern African shield. Volcanicity and sedimentation, was followed by gravity-induced deformations on a large scale, resulting in the development of major folds and faults which retained the northeast-southwest-trending grain of the depository. The deformation produced more synclines than anticlines, the latter usually being faulted out along the major strike faults or slides. The shape of the greenstone belt was subsequently modified by episodic granite intrusion, and the typical arcuated schist belts were developed (the "granite-greenstone pattern" of Anhaeusser and others, 1969). The most important deforming granites were the diapiric plutons, typified by the Kaap Valley Granite (see Figure 1). This granite produced and intensified structures, both major and minor, in the main gold-producing areas of the greenstone belt (Roering, 1965; Anhaeusser, 1965, 1969). Of importance economically, are the transcurrent faults caused by reactivation of pre-existing longitudinal faults. Regenerative stresses, in the form of second-order phenomena associated with the wrench-fault tectonics, were largely

responsible for producing structures suitable for subsequent ore deposition. The importance of the major faults in the development and distribution of gold mineralization in the Barberton Mountain Land has been demonstrated by the fact that by far the greatest number of mines and prospects are scattered along, or immediately adjacent to, the fault traces. It has been possible, in a number of instances, to trace major faults from well-exposed areas, into regions where exposure is poor, merely by taking into account the presence of gold workings and old prospect shafts.

10. A great variety of granitic rock-types surround the Barberton Mountain Land. The diapiric granites are among the oldest and range in age between 3.2–3.4 b.yrs. (E. Oosthuyzen; R. Davies; personal communication, 1969). Structurally, they possess foliated, often lineated margins, and contain aligned xenoliths and fragments of the greenstone belt. Away from the contacts the granite generally loses its gneissic texture and becomes relatively homogeneous. The Kaap Valley Granite, like all the diapiric bodies in the area, is characteristically soda-rich and has been classified as a hornblende tonalite. Petrologically the rock contains more hornblende and biotite than most other granites in the area, suggesting that its composition was influenced by the stoping and assimilation of mafic and ultramafic supracrustal rocks into which it intruded. The Kaap Valley Granite is also characterized by the absence of a pegmatitic phase (Anhaeusser, 1969). A number of leuco-biotite tonalitic gneisses displaying similar structural and chemical characteristics as the Kaap Valley Granite have also been described by Viljoen and Viljoen (1970f).

The Nelspruit Granite terrain consists of a complex assemblage of potash-rich gneisses, migmatites, homogeneous high-volatile granites, granodiorites, adamellites, and pegmatites. Part of the migmatitic terrain may constitute an original basement although consistent geochronological ages younger than the diapiric granites are obtained. These ages may, however, reflect a superimposed metamorphic event at $\sim$3000 million years. The most comprehensive accounts of these granites are those of Hunter (1957; 1961; 1965; 1968), Visser and others (1956), Anhaeusser (1966; 1969), and, more recently, Viljoen and Viljoen (1970f, g).

The youngest granitic rocks in the area are homogeneous, often porphyritic, coarse-grained, potash-rich, magmatic granites. They have a distinctive cross-cutting mode of emplacement and truncate all earlier formations into which they intrude. Numerous descriptions of these granites are available (Visser and others, 1956; van Eeden and Marshall, 1965; Hunter, 1957, 1965, 1968; De Gasparis, 1967; Anhaeusser and others, 1968; Anhaeusser, 1969). Recently Viljoen and Viljoen (1970f, g) divided the young granite plutons into two groups based on their chemistry and their age. The older variety have a provisional age of 2.80 b.yrs. (E.J. Oosthuyzen, personal communication, 1969) while the younger plutons range in age from 2.20–2.65 b.yrs. (Allsopp and others, 1962; De Gasparis, 1967). Chemically, the older plutons have less potash than the later varieties which show abundant, coarse, pinkish-red microcline felspar. Isolated occurrences of late syenite intrusions have also been reported (Viljoen and Viljoen, 1970f).

The various granitic rocks constitute a granite series, the oldest tonalitic gneisses being soda-rich, and passing progressively, with decreasing age, into granites rich in potash (Anhaeusser, 1969; Viljoen and Viljoen, 1970g). The latter authors found that the older granites also contain lower Rb and higher Sr contents than the later granites.

11. The emplacement of the diapiric granites resulted in the development of a complex structural history for the greenstone belt, brought about by the superimposition of a number of periods of folding (Ramsay, 1963; Viljoen, 1964; Anhaeusser, 1964 and 1969; Urie, 1965; Roering, 1965). North of Barberton, for example, the emplacement of the Kaap Valley Granite resulted in the development of at least four separately identifiable phases of deformation. Deformations F1 and F2 were closely related in time and produced a strong schistosity, superimposed on to which is a pronounced stretch lineation. Deformation F3 caused arcuation of the Eureka and Ulundi Synclines and was responsible for the northwest-southeast fold trend in the Consort Mine area. The last deformational event (F4) caused the development of flat-folds and conjugate folds, indicating a uniform vertical stress-field throughout the area (Anhaeusser, 1969).

The structural history outlined above can also be followed step by step petrologically by examining thin sections of the metamorphic rocks in the area. The metamorphism produced by the emplacement of the granites caused mineral reorientation, and several periods of mineral development and deformation, as well as post-tectonic recrystallization. Some retrograde metamorphism occurred in the waning phases of metamorphism (Anhaeusser, 1969).

12. Mineralization in the Barberton Mountain Land is almost invariably structurally controlled. On a regional basis the optimum development of gold mineralization occurs in the area

where the interplay of the following three main factors was at its greatest : (i) the availability of suitable source rocks (ii) the availability of suitable granitic intrusives providing temperature-pressure gradients sufficient to mobilize the mineralization, and (iii) the availability of suitable structures to trap auriferous solutions. From the regional distribution of the gold and silver mineralization it appears that the area of optimum mineralization occurs on the northwest flank of the Barberton greenstone belt. Here the source rocks for the gold are believed to have been the early mafic and ultramafic assemblages of the Onverwacht Group. The deformation associated with the Kaap Valley Granite emplacement provided a favourable structural environment in the competent Fig Tree and Moodies assemblages while the latter granite, as well as the Nelspruit Granite, supplied the necessary pressure-temperature conditions for the mobilization and concentration of the mineralization (Anhaeusser, 1969).

Geochemical investigations of the different rock-types on the southern side of the Barberton greenstone belt by Viljoen and others (1969), have revealed that the gold of the deposits in this area had its ultimate source in the ultramafic-to-mafic volcanics (0.005-0.02 ppm Au) and not in the intrusive granite (<0.005 ppm Au).

Economic deposits of chrysotile asbestos (van Biljon, 1964) and magnesite are restricted to the differentiated ultramafic bodies where the controlling factors appear to be the development of high-magnesium dunites or peridotites, superimposed on to which is a complex structural history of folding and faulting. The ultramafic rocks, where intruded by porphyry bodies, or where sheared, often give rise to talc deposits. Traces of nickel mineralization also appear to be restricted to these rocks. Iron ore deposits have resulted from processes of secondary enrichment of folded banded ironstone, shale, and banded cherts (Bursill and others, 1964). Small barytes deposits appear to be associated with quartz-sericite and other altered felsic tuffs. The close association of the barytes with these rocks has led Viljoen (1970) to suggest a close genetic relationship between the two.

EVOLUTIONARY MODEL OF THE DEVELOPMENT OF THE BARBERTON GREENSTONE BELT

The combined efforts of a number of investigators, each following and applying different geological disciplines have contributed to the understanding of the evolutionary development of the Barberton greenstone belt. The earliest model formulated for this area attempted to compare the volcanic assemblages with the ophiolites, or initial magmatic phase, of a geosyncline or island arc, while the sedimentary successions were compared with the flysch and molasse assemblages, also of geosynclines (Anhaeusser and others, 1968). Continued studies resulted in a revised model being erected whereby the Barberton experience was used in an attempted reappraisal of Archaean granite-greenstone terrains of the shield areas of the world (Anhaeusser and others, 1969). The main conclusions drawn by these authors are still believed to maintain, although minor refinements to the scheme have been suggested by Viljoen and Viljoen (1970h).

Of considerable importance is the stratigraphic model, with its lower ultramafic-to-mafic volcanic and igneous assemblages and its upper mafic-to-felsic volcanic and pyroclastic successions. Included with these distinctive associations are the rocks of lesser abundance, whose characteristic properties nevertheless enable them to be linked diagnostically to specific positions in the developing stratigraphic pile. The volcanic phase is followed by a terminal sedimentary phase, the latter being subdivided into an early, essentially argillaceous succession and a later, predominantly arenaceous succession.

The supracrustal rocks of the greenstone belt are surrounded by a variety of granite-types each with its own distinctive chemistry, mode of emplacement, outcrop style, metamorphic overprint, and deformational characteristics. Three main granite-suites are recognized, the oldest being the diapiric tonalites, followed by the more volatile granodiorites, gneisses, and migmatites and, finally, the younger granite plutons.

Other features of the model concern the disposition of the various types of mineralization with respect to host-rocks, mobilizing agencies, and structural, and lithologically favourable ore-traps. In addition, the model attempts to relate the mega-structural phenomena of the belt to processes of gravity deformation, the latter being coincidental with the upward movement of the enveloping granites.

THE APPLICATION OF THE BARBERTON MODEL TO WESTERN AUSTRALIA

Projecting the Barberton experience to the Archaean geology of Western Australia will, it is contended, assist considerably in the development of a better understanding of the principles and processes operative in this cratonic granite-greenstone environment. Having seen a large proportion of the Pilbara and Yilgarn regions of Western Australia, the writer was impressed by the remarkable degree of similarity of the rocks, and their associations, with those of their South African counterparts. Due, however, to factors such as poor exposure, poor rock preservation, and poor outcrop continuity, difficulties are clearly being experienced in formulating suitable models depicting the geological history and development of the Western Australian granite-greenstone environment. It is not the intention here to criticize or reorganize the Archaean geology of Western Australia. This will no doubt be adequately accomplished in the future by local investigators. What will be attempted, however, is a demonstration of the possible applicability of aspects of the Barberton model to some of the areas seen on the Western Australian shield.

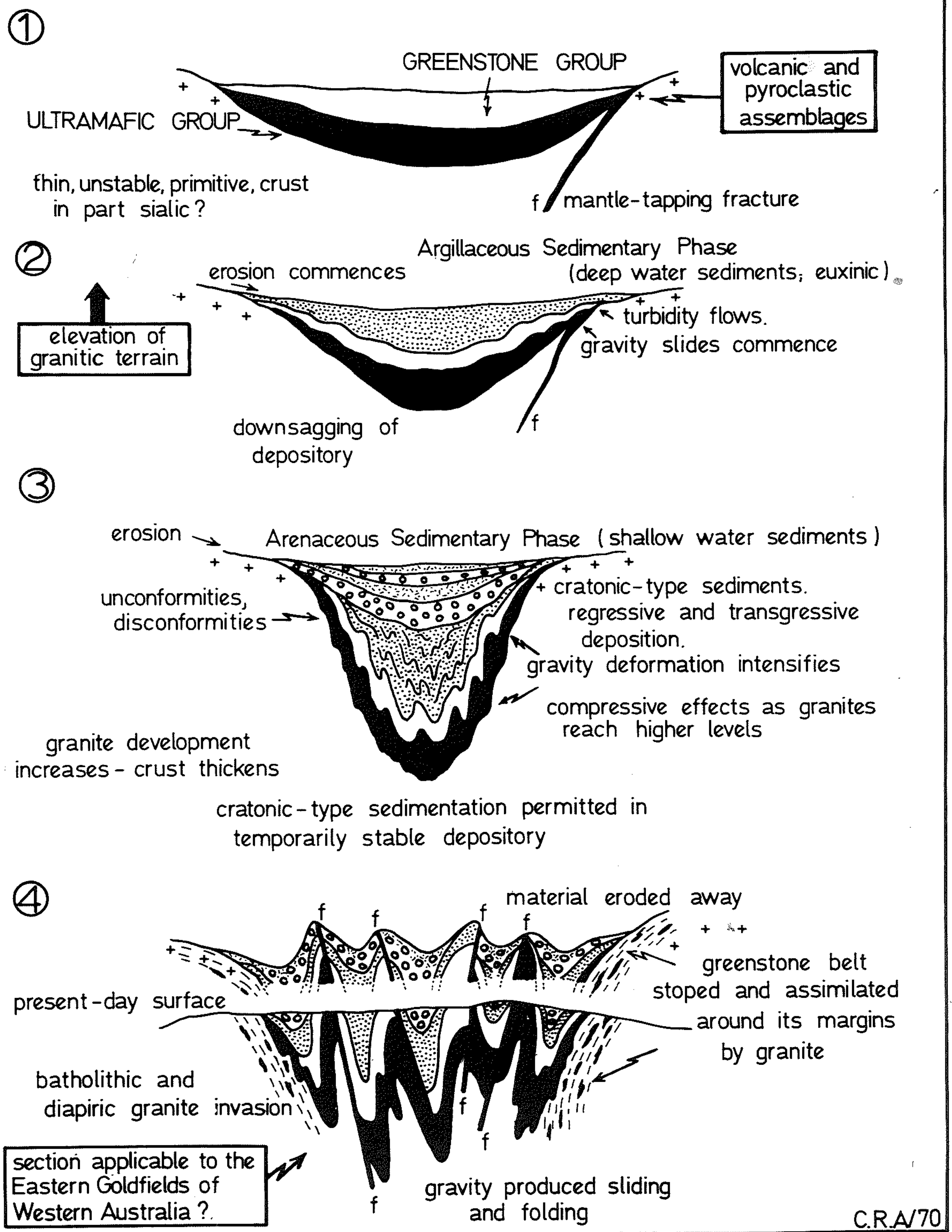
A. The Eastern Goldfields, Yilgarn Block

Probably the most complete greenstone belt in Western Australia occurs in the Eastern Goldfields region of the Yilgarn Block. The writer is of the opinion that practically all the elements of the Barberton model can be recognized in one place or another between the towns of Menzies in the north and Norseman in the south. One of the main problems, and one which restricts any attempt at a regional understanding of the distribution of the various rock-types in the area, appears to be connected with inadequate information relating to the structural history of the region as a whole. Just as in Southern Africa, the greenstone belts of Western Australia have a very pronounced linear orientation. This well-defined north-northwest alignment corresponds to the earliest recognizable structural deformation suffered by the Archaean greenstone belt successions. In addition, this early event was responsible for the numerous major synclinal and anticlinal structures so clearly seen from the air or on aerial photographs. If, as is considered to be the case in the Barberton Mountain Land, this early deformation was largely gravity induced on a thin, unstable crust, then the structural pattern produced may closely resemble that of the Barberton example. The deformation would, typically, result in the development of large, essentially isoclinal folds and contemporaneous faulting. These faults, which are probably in effect tectonic slides, conceivably extend for great distances and parallel the regional trend of the greenstone belts (see Fleuty, 1964, for definition of tectonic slide). As in the Barberton area, and in many other greenstone belts two or more synformal structures often occur together, without complementary antiforms and the adjacent steeply dipping limbs of these synforms appear to be separated by dislocations (Anhaeusser and others, 1969). The juxtaposition of syncline with syncline can clearly be demonstrated in the Barberton area where each major structure often displays rock-types of a totally different character from the next. The synclines may thus expose differing, yet juxtaposed, sections from the various parts of the greenstone belt stratigraphy.

The rapid stratigraphic changes seen in sections from east to west across the Eastern Goldfields greenstone belt strongly suggests that repeated folding has taken place. This folding is probably of an isoclinal nature, and may well be coupled with numerous longitudinal strike faults. As gold mineralization has been a feature of many Western Australian greenstone belts it is suggested that a plot of all the known prospect pits, and occurrences of gold derived from vein quartz lodes may, as is the case in the Barberton region, provide clues necessary to define numerous obscure fault traces. Apart from quartz veins and obviously sheared and schistose rocks, another feature typical of many fault zones, and particularly evident in the volcanic successions, is the presence of strongly carbonated rocks. Bearing in mind these factors, it may be possible to locate many more faults than there are known at present in the area. The rapid changes as well as duplications of the stratigraphy may find a ready explanation if the structure is better understood. In Figure 3 an attempt is made to diagrammatically illustrate the evolution of a greenstone belt as well as some of the conditions that may prevail in a section across the Eastern Goldfields. All the surface manifestations presently observed can, it is contended, be readily explained by bearing in mind that the area has been subjected to considerable folding and faulting. The style of deformation (essentially that of gravity induced downsagging of the depository) can produce intense deformation in one area and remarkably undisturbed successions in another. It is not uncommon, therefore, to find pillow structures, amygdales, spherulites, cross-

FIGURE 3

SIMPLIFIED DIAGRAMMATIC MODEL SHOWING THE EVOLUTIONARY DEVELOPMENT OF AN ARCHAEAN GREENSTONE BELT



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bedded structures, ripple-marks, flute casts, and a host of other sedimentary and volcanic structures, occurring in a well-preserved state in rocks which, only a few feet away, display signs of considerable structural disturbance.

Apart from the major structures developed in the greenstone belts there are numerous other structures, the trends of which deviate from the more linear, regional trends. These superimposed trends owe their origin to the great variety of granite types that intrude the greenstone belt and cause local disruption of the formations. In the area east of Norseman, for example, a tonalitic gneiss containing mafic schlieren aligned parallel to the contact of the adjacent greenstone belt, has caused a considerable realignment of the earlier north-northwest-trending volcanic and sedimentary formations. This tonalitic gneiss is typical of the early diapiric granites that are responsible for much of the structural complexity in parts of the Barberton region. The example near Norseman, and seen in a number of places, including the Buldania rocks area, demonstrates a pronounced foliation and steeply dipping lineation in the areas bordering the contact with the greenstone belt, which, in turn, encircles the tonalitic pluton in a broad arc extending from southwest to northeast. The structural effects of this diapiric granite appear to extend well into the greenstone belt and may even be responsible for the arcuation of the stratigraphy in the neighbourhood of the Mission Sill, west of Lake Cowan. Numerous other examples exist of structures produced by the intrusion of similar diapiric plutons but since they are generally poorly exposed difficulties will be encountered in trying to establish the precise nature of these granites. Much of the structure is also modified by large batholithic granite bodies that appear to be gneissic granodiorites. These batholiths behave similarly to the gregarious batholiths developed on the Rhodesian craton and described by Macgregor (1951).

The most important aspects of the geology of the Eastern Goldfields area of Western Australia, when compared with the Barberton Mountain Land, concern the similarities encountered in the stratigraphy of these two areas. Parts of practically the entire Barberton stratigraphic model can be identified in a number of different localities, but no single area is known to the writer where the full succession can be studied uninterruptedly from base to top. The lowermost as well as the uppermost formations of the stratigraphy are particularly well-developed on the western limb of the Kurrawang Syncline, a major structure occurring between the towns of Kalgoorlie and Coolgardie. Glikson (1968) has divided the geology of this area into three main successions on the basis of lithological associations. The first and lowermost assemblage, referred to as the Coolgardie Ophiolites, comprise approximately 20,000 feet of pillowed and massive metabasalts, stratiform meta-dolerites, amphibolites, serpentinites, meta-pyroxenites, minor stratiform soda meta-porphyries, and thin intercalations of shale. The base of the succession is intruded by granite while the top merges into what have been called the Mungari Beds, by means of a progressive increase in argillaceous intercalations. The Mungari Beds are estimated by Glikson (1968) to be approximately 32,500 feet thick, of which about two-thirds consist of meta-sediments and one third of meta-volcanic rocks. The lowermost members of the succession are characterized by meta-argillites and metabasalts. These pass upwards into laminated turbidite sediments and the uppermost successions are comprised of massive and banded greywackes, argillites, and minor conglomerates. Overlying this assemblage is the succession referred to as the Kurrawang Beds, and which has an inferred thickness of about 7,500 feet. Polymictic conglomerates and greywackes constitute the bulk of the succession, there being no argillaceous sediments or volcanic members present.

The preponderance of ultramafic and mafic rocks and the limited development of felsic volcanics and sediments suggests a close analogy between these rocks and those of the lower half of the Barberton stratigraphic column. Analyses of some mafic rocks from the Coolgardie area, cited by Joplin (1963) and Glikson (1968), show that the basaltic rocks from the area range in composition from komatiite varieties through to oceanic tholeiites and even some continental tholeiites. Analyses of serpentinites and pyroxenites associated with the basalts are also listed by Glikson (1968). Further support suggesting that some of the successions in the area may form part of the Ultramafic Group lies in the fact that intrusive soda-rich porphyry bodies also occur within them (Glikson, 1968). In addition, the writer was shown quartz-fuchsite-schists, interlayered with ultramafic and mafic rocks in the Comet Hill Syncline south of Coolgardie.

The volcanic rocks of the Mungari Beds are similar in composition to average tholeiitic andesites, and probably constitute the lower part of the Greenstone Group of the Barberton model. The mafic-to-felsic assemblages characteristic of the bulk of this group are, however, absent. Instead the sedimentary rocks of the Mungari Beds probably represent the earliest argillaceous members of the Sedimentary Group while the Kurrawang Beds constitute the more arenaceous phases.

Elsewhere in the Eastern Goldfields, rocks typical of the Ultramafic Group occupy a narrow belt extending from Menzies in the north through Kalgoorlie, Kambalda, and Widgiemooltha, to Norseman. In the latter area, numerous quartz-sericite-schists occur interlayered with basaltic komatiites and tholeiitic basalts. Similar relationships can be seen in selected exposures along the western margins of Lake Cowan and Lake Lefroy. The lithological correlation suggested is supported by a number of chemical analyses carried out on mafic rocks from the Yilmia Hills area (J. Hallberg, personal communication, 1969, and quoted in Anhaeusser, 1970). In addition, an analysis of fine-grained serpentinized peridotite from the Hannan's Lake-Mt. Hunt area near Kalgoorlie, compares closely to that of peridotitic komatiite from the Barberton region (analysis quoted in Anhaeusser, 1970).

A possible equivalent of the Middle Marker, which in the Barberton region separates the Ultramafic Group from the Greenstone Group, may be represented in the Eastern Goldfields by the Kapai slate horizon. This approximately 20 feet thick pyritic, carbonaceous, shale band is often cherty or siliceous and can be traced from near Kalgoorlie, southwards, through the Hannan's Lake-Mt. Hunt area, towards Lake Lefroy. In the Hannan's Lake area the Kapai slate is bounded on the west by the Hannan's Lake serpentinite (peridotitic komatiite referred to earlier) and the Devon Consuls basalt, while to the east it is overlain by the Paringa basalt.

The most common rock-types in the Eastern Goldfields are those characteristic of the Greenstone Group and constitute a wide variety of mafic-to-felsic volcanic and pyroclastic rocks. Cyclical volcanicity is particularly evident in these rocks and can be used to good advantage in determining the directions of younging of the successions as well as providing additional control for mapping purposes. An accurate assessment of the nature of the rock associations present in cycles makes it possible to derive some estimate of the stratigraphic position of the region with respect to the total stratigraphic pile which includes the Ultramafic Group, the Greenstone Group, and the Sedimentary Group assemblages (see hypothetical stratigraphic column, Anhaeusser, 1970). Exposures of mafic-to-felsic rocks of the lowermost part of the Greenstone Group occur in a number of different localities along the western edges of Lake Cowan and Lake Lefroy, in the region around Coolgardie, and in the Menzies-Mt. Ida region (viz: Menzies Syncline, Kurrajong Anticline, and Snake Hill area). Cyclic volcanicity typical of a stratigraphically higher position can be seen north of Kanowna (Harper Lagoon) in the Kurnalpi area, and in the Mount Thirsty area, west of Lake Cowan.

Assemblages typical of the uppermost phases of the Greenstone Group occur in the Kurnalpi area near the Kanowna town dam and extending eastwards to the old ghost town of Bulong. Rock-types occurring in the latter environment mainly include a variety of well-exposed felsic tuffs, agglomerates, quartz felspar porphyries, and dacitic-to-rhyolitic volcanic rocks. Lesser amounts of tholeiitic basalt, gabbro, and pyroxenitic gabbro are also present. Felsic volcanic and pyroclastic rocks, occupying a position high up in the regional stratigraphic column, also occur in the Yindarlgooda Lake area. Substantial chert horizons, terminating mafic-to-felsic cycles, are developed near Rocky Downs.

Shales, greywackes, conglomerates, and banded iron formations, typical of the argillaceous phase of the Sedimentary Group, occur immediately east of Norseman and probably occupy a fault bounded block as the sediments in their present position are incompatible with their enclosing Ultramafic Group volcanic rocks. Other fine argillites showing graded-bedding and turbidite structures occur in the Widgiemooltha area. Near the Cardiff Castle Mine laminated cyclic beds consisting of shales, jaspilites, conglomerate pebbles, mud flakes, and greywackes, occupy an approximately 500 feet thick zone bounded by mafic volcanic rock-types. The presence of gold mines in the immediate vicinity suggests that faulting may once again be responsible for the present disposition of these sediments.

An arenaceous phase terminates the Sedimentary Group and rocks falling into this category include the Kurrawang Beds in the Coolgardie area (Glikson, 1968), and the well-exposed conglomerates in the Lake Lefroy and Kurnalpi areas.

Differentiated igneous bodies occur interlayered with the volcanic successions but, unlike the Barberton examples, appear to represent the fractionated products of magma of tholeiitic parentage. No differentiated ultramafic bodies have been recorded in the Western Australian Archaean, their absence probably accounting for the paucity of chrysotile asbestos occurrences. The rock-types associated with the differentiated bodies such as the Mount Thirsty Sill, the Mission Sill, and the Bulong Complex, comprise serpentinites and pyroxenites at the base, passing upwards into gabbros and granophyres near the top. Being enclosed in rocks of the Greenstone Group these bodies probably represent penecontemporaneous sills comprised of magma of the same bulk composition as that of the surrounding volcanic cycles.

B. Other Western Australian Areas

The Barberton model, or parts of the model, can also be applied to other greenstone belt occurrences in the Yilgarn and Pilbara regions of Western Australia. Space, however, does not permit elaboration of their geology but of all the other areas seen by the writer none appeared to have rock assemblages that could be regarded as constituting part of the Ultramafic Group. Instead most of the successions represent parts of the Greenstone Group. This appeared to be the case in the Murchison area between Tallering, Yalgoo, Mt. Magnet, Cue, and Meekatharra. Mafic-to-felsic volcanic assemblages predominate, with ultramafic rocks constituting only a low percentage of the total. Volcanic cyclicity is again well-developed in these greenstone belts (Anhaeusser, 1970).

In the Pilbara region the rock-assemblages appear to be mainly representative of the Greenstone Group with mafic-to-felsic cycles capped by major chert horizons such as those near the town of Marble Bar. Ultramafic rocks, although present, constitute only 10-15 per cent of the total stratigraphic pile. The granites in the Pilbara area behave similarly to the large gregarious batholiths of Rhodesia and may be held responsible for the assimilation of the early Ultramafic Group assemblages. Not much is known about these granites or their chemistry but they have clearly played an important structural role in the evolution of the greenstone belts of this region.

C. Concluding Remarks

A few notes of caution should be added before closing this discussion of the Barberton model and its applicability to other areas. Although a pattern has emerged which appears to be useful in dealing with problems of greenstone belt geology care must still be taken in applying the model. In this respect the writer expresses disagreement with a recently attempted unsighted correlation by Viljoen and Viljoen (1970h) of the Barberton model with the geology of the West Pilbara Goldfield based on descriptions of the area by Ryan and Kriewaldt (1964). Although the rocks in this area may be of Archaean age they did not appear to the writer to possess the characteristics of greenstone belt geology, nor were they like the successions developed in the East Pilbara area centred around the town of Marble Bar. Photogeological studies of the Whim Creek - Mons Cupri area have confirmed the field observations that no pattern typical of greenstone belt circumstances can be ascribed to the region. Other unsighted attempts at a litho-stratigraphic correlation of the Coolgardie-Kurrawang area with the Barberton model by Viljoen and Viljoen (1970h) are of interest but are also open to criticism.

Finally, in summing up this presentation it is the writer's contention that the Barberton granite-greenstone model, provided it is used judiciously, can assist materially in the development of a better understanding of the geology and historical circumstances pertaining to the Archaean granite-greenstone geology of Western Australia as well as to other shield areas of the world.

ACKNOWLEDGEMENTS

The writer wishes to express his gratitude to the many people in Western Australia who made it possible for him to get a glimpse of the Archaean geology of the Pilbara and Yilgarn regions of the State. In particular I would like to thank Mr. J.H. Lord, Director of the Western Australian Geological Survey for having made it possible for me to undertake visits into the field with members of his staff. Many thanks are also extended to Dr. G.J.H McCall for the interesting discussions held with him at the University of Western Australia, and in the field.

In addition, I would like to thank the geological staffs of the following mining companies in Western Australia - all of whom went out of their way to make my stay interesting and who were of assistance to me in every way possible : C.R.A. Exploration (Pty.) Ltd.; Western Mining Corporation; Anaconda Australia; Utah Development Company; Pickands Mather International; Hamersley Iron, and R. Hare and Associates (Metals Exploration).

Thanks are also extended to Mr. R. Mason for his comments and criticisms of the draft, and to Mr. K.A. Viewing for having presented the paper on the writer's behalf in Perth.

Finally, I would like to thank the C.S.I.R. in Pretoria, the University of the Witwatersrand, and the Economic Geology Research Unit, both in Johannesburg, for funds enabling me to undertake the study tour of Western Australia.

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