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The Evolution of the Early Precambrian Crust of Southern Africa

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The evolution of the early Precambrian crust of southern Africa

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CONTENTS

The early Precambrian granite–greenstone basement complex of Rhodesia and South Africa constitutes one of the oldest known fragments of the Earth's crust. Scattered within the expanse of granitic rocks are numerous greenstone belts some approaching, or even possibly exceeding, ages of about 3400 Ma. These ancient greenstone belt remnants represent the earliest clearly decipherable geological events on the Earth's surface, and any evidence concerning the nature and evolutionary development of the primitive crust must be sought largely from an examination of their lithologies.

The stratigraphy of the early greenstone occurrences in southern Africa is described with particular emphasis being given to the geological record established in the well-preserved Barberton Mountain Land of the Transvaal. The evidence for a primitive sialic versus simatic crust is reviewed and reference is made to the reported pre-greenstone belt basement remnants found in Rhodesia as well as in Swaziland. Comparisons are drawn between the early greenstone belts and modern island arcs, use being made of available geochemical data from the two environments.

It is concluded that the early crust in southern Africa had analogies with the present-day abyssal regions of the oceans. Progressive transformation, involving island arc-like development and protocontinental nucleation, resulted from processes involving partial melting of the primitive lithosphere coupled with the secular mixing of mantle derived, granitic additions. The early thin, unstable, primordial crust underwent progressive thickening processes and, about 3000 Ma ago, stabilized sufficiently to permit the development of the first interior or cratonic-type sedimentary basins. Increases in the areal extent of the developing basins are briefly traced and the more significant events, from the earliest Precambrian to middle Proterozoic times (*ca.* 1700 Ma ago), are contrasted and summarized.

1. Introduction

The nature and composition of the primitive crust of the Earth and the origin of continents has been widely debated over the years by a great number of Earth scientists, each attempting to seek solutions to the problems by formulating hypotheses based on the ever increasing geophysical, geochemical and experimental data being made available to them. Inevitably, as is the case with such enigmatic yet fundamental problems, like those relating to the origin and evolution of the Earth's crust, a great number of theories have been submitted for consideration and, as yet, no general agreement has been reached. As summarized by Glikson (1971) the various postulates alternatively suggest a primary acid crust, a primary basic crust, a primitive anorthositic crust, nucleation of granites through mantle differentiation episodes, development of the sial crust through sedimentary differentiation of a basic crust, primordial plate tectonics and early island-arc-like lineaments in either an original acid or an original basic crust.

The most popular current hypotheses of continental origins and evolution still appear to be those outlined nearly a decade ago by Engel (1963). The one postulates a thin crust of continental (granitic) rock formed very early in the Earth's history, during relatively rapid differentiation of the Earth into core, mantle and crust, while the other theorizes that the primordial differentiation was less complete and resulted in the development of a protocore, a protomantle and oceanic (basaltic) crust.

A mass of information has been advanced to support the various hypotheses but there appears to be a notable paucity of contributions to this theme emanating from researchers who have investigated the Earth's oldest shield areas. The advances being made in the early Precambrian granite-greenstone terrains of Canada, Western Australia and southern Africa are, however, likely to correct this imbalance. The African subcontinent is particularly suitable for the study of early Archaean ($\geqslant$ 3400 Ma) to early Proterozoic ($\approx$ 1700 Ma) geology having, as it does, a relatively unblemished record of this period in Earth history available in Rhodesia and the Transvaal.

The exceptionally well-preserved Barberton Mountain Land has, for example, provided the basic data used to formulate several geological models of early Precambrian granite-greenstone evolution (Anhaeusser *et al.* 1968, 1969; Viljoen & Viljoen 1969*e*). The area also holds considerable promise as one in which the evolutionary history of the crust may be traced. From a comprehensive analysis of the greenstone belt itself, clues to the pre-greenstone belt environment can be sought. Coupled with this, an investigation of the granite terrain surrounding the Mountain Land may, in the future, supplement our knowledge of crustal development and evolution. In this paper it is the intention to review the main features pertaining to the geology and evolution of the earliest greenstone belt occurrences and to examine the evidence presently available relating to the possible nature of the pre-greenstone belt environment. Lastly, it is proposed to trace briefly the geological development of the cratonic areas in post-greenstone belt times with particular consideration being given to the changes in crustal stability, lithology, structure, and metamorphism.

2. Early Archaean crustal development

The earliest decipherable events – the greenstone belts

In southern Africa the oldest rocks are developed mainly on the Rhodesian and Kaapvaal (Transvaal) cratons which together constitute part of the ancient crystalline shield. The discussions dealing with the development of the early crust will therefore relate almost entirely to this region. The two cratonic nuclei in their present form consist of Archaean granite–greenstone complexes together with cover sequences and both are encircled by younger, curvilinear metamorphic mobile belts such as the Zambesi, Mozambique, Limpopo and Namaqua–Natal mobile belts (Anhaeusser *et al.* 1969).

The volcanic and sedimentary piles that comprise the greenstone belts of the Rhodesian basement complex have been grouped into three major subdivisions referred to as the Sebakwian, Bulawayan and Shamvaian groups respectively (Macgregor 1951; Swift 1961; Bliss & Stidolph 1969; Wilson, this volume, p. 389). At the base the Sebakwian stratigraphy consists of a variety of mafic and ultramafic rocks with sedimentary interlayers and is characterized by the presence of intrusive masses of ultramafic rock which have been classed into the so-called Magnesian series – a name reserved by Macgregor (1951) for a suite of late Sebakwian intrusive ultramafic rocks. In many places the group has been extensively invaded, fragmented, and often apparently granitized by the intrusion of a wide variety of granitic rock-types. Basic lavas, often pillowed, together with andesitic breccias and interbedded sediments constitute the overlying Bulawayan group, the latter in turn being overlain by the Shamvaian group which is comprised of quartzites, conglomerates, greywackes and shales.

More recently, rocks regarded as older than the Sebakwian group have been recognized in the Selukwe area by Stowe (1968*a*, *b*). These apparently consist of scattered remnants of mafic and ultramafic rocks together with banded ironstones and occur throughout the gneisses and migmatites to the southwest of Selukwe.

On the Kaapvaal craton rocks of an essentially similar character to those of the Rhodesian greenstone belts are found scattered about in a vast 'sea of granite' and are exposed in areas stripped of their younger cover sequences. These greenstone occurrences are collectively referred to as remnants of the Swaziland Sequence, the latter being particularly well developed in the Barberton Mountain Land and discussed later in greater detail. Most of the Archaean remnants in the Transvaal generally consist of a variety of mafic and ultramafic rocks with sedimentary members either absent entirely, e.g. the remnants exposed on the Johannesburg–Pretoria granite dome (Anhaeusser 1971*b*), or only poorly developed, as in the Murchison and Pietersburg greenstone belts. However, apart from these and the Barberton occurrence, not much is known of the remaining greenstone relics on the craton.

As in the case of Rhodesia an assemblage of rocks, claimed to be older than the Swaziland Sequence, has been described by Hunter (1970). Referred to as the ancient gneiss complex, this suite of metamorphites, which include kinzigites, quartzites, taconites, amphibolites, siliceous diopside-bearing granulites, ultrabasic rocks and extensive tonalitic gneisses and migmatites, occurs to the east of the Barberton Mountain Land in Swaziland.

The Barberton Mountain Land and surrounding granite terrain

One of the best documented greenstone belts in southern Africa occurs in the Barberton area of the eastern Transvaal Lowveld. Due to its extreme age and exceptional preservation it has been the focus of a number of specialized studies, many of which are still in progress. The availability of a wealth of new chemical and geological data makes this greenstone occurrence the obvious starting-point in any discussion enquiring into the evolution of the southern African crust. The geology of the region has been the subject of continuing interest since Hall first mapped the area in 1918. Important early contributions were made by the Geological Survey of South Africa (Visser *et al.* 1956), and the Swaziland Geological Survey (Hunter 1961). More recently, there have been a spate of publications following studies in the area by members of the Economic Geology Research Unit of the University of the Witwatersrand and officers of the South African Upper Mantle Project. Selected publications dealing with aspects of the stratigraphy include Anhaeusser *et al.* (1968), Anhaeusser (1969, 1971 *a*, *c*, *d*), Condie, Macke & Reimer (1970), and Viljoen & Viljoen (1969*a*, *b*, *d*; 1970*a*, *b*). Papers dealing with granitic rocks include those of Hunter (1957, 1961, 1970, 1971), Visser *et al.* (1956), Anhaeusser (1966, 1969, 1971 *a*), Roering (1967), Engel (1968), and Viljoen & Viljoen (1969*c*, *f*). Comprehensive summaries of the main features arising out of the investigations in the Barberton Mountain Land are available (Viljoen & Viljoen 1970*a*; Anhaeusser 1971 *d*), and it is the intention here to outline only briefly the geology of the region

(i) *The Swaziland Sequence*

The Barberton greenstone belt comprises a wide variety of volcanic, igneous and sedimentary rock-types that have collectively been grouped into the Swaziland Sequence. The Onverwacht group, developed at the base of the sequence attains a thickness in excess of 15 km and has been subdivided by Viljoen & Viljoen (1969*d*) into six formations (see figure 1).

The lower three formations are referred to collectively as the *lower ultramafic unit*, being characterized by a relative abundance of ultramafic rocks which, together with the majority of associated mafic volcanic rocks, are distinctive in their high MgO content, high Ca/Al ratio and low alkalis, particularly K_2O. The assemblages are not comparable with any well-established class of ultramafic or basaltic rock-types and they have been assigned the name 'komatiite' (Viljoen & Viljoen 1969*a*). Examples of the major element geochemistry of basaltic and ultramafic komatiites and interlayered aluminous felsic schists in the *lower vliramafic unit* are provided in table 1.

A persistent sedimentary horizon termed the middle marker (Viljoen & Viljoen 1969*b*) occurs at the top of the lower ultramafic unit and heralds an abrupt change in the type of volcanicity that occurs in the upper three formations of the Onverwacht stratigraphy. Known collectively as the *mafic-to-felsic unit*, the upper formations consist of cyclically alternating mafic and intermediate to acid volcanics together with a wide variety of pyroclastic rocks. Individual volcanic cycles generally commence with wide zones of tholeiitic basalts that are invariably overlain by thinner zones of dacitic to rhyolitic lavas, the latter frequently being capped by chert and ferruginous chert horizons, some of which attain thicknesses of up to 180 m (Viljoen & Viljoen 1969*b*). Ultramafic bands and lenses also occur sporadically throughout the successions but are volumetrically of minor importance. Progressive changes in the major element chemistry of the tholeiitic basalts and felsic volcanics is apparent stratigraphically upwards and is demonstrated in table 1.

In several localities within the lower ultramafic unit, a number of layered differentiated ultramafic pods and sills are developed, the latter consisting of dunites, harzburgites, peridotites, pyroxenites, gabbros, norites and anorthosites (Anhaeusser 1969, 1972; Viljoen & Viljoen

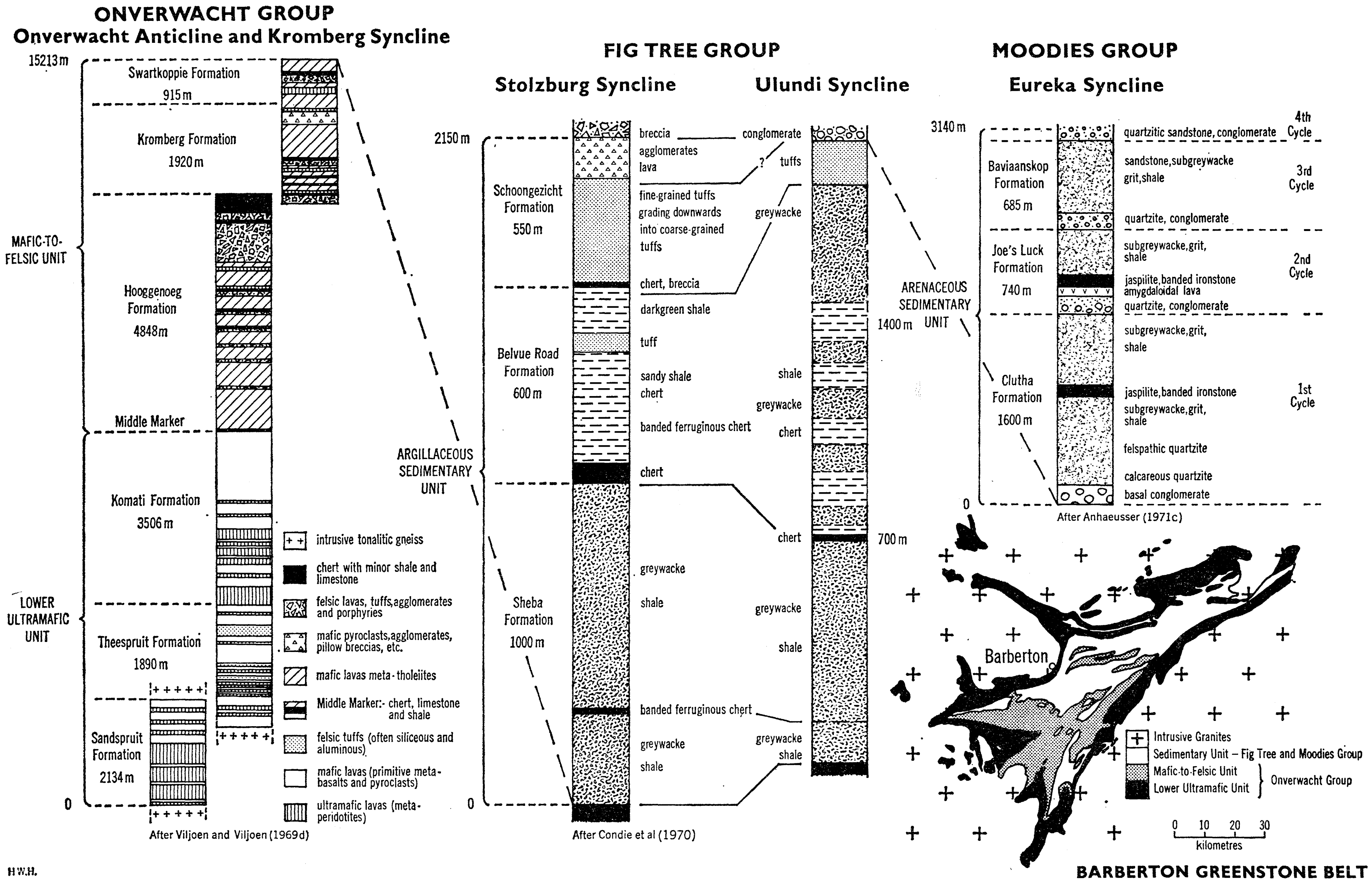

Figure 1. Stratigraphic sections depicting the various volcanic and sedimentary successions of the Swaziland Sequence in the Barberton Mountain Land, South Africa. The distribution of the lower ultramafic unit, the mafic-to-felsic unit, and the combined sedimentary units are shown in the inset general geological map of the early Precambrian (⩾ 3400 Ma old) Barberton greenstone belt.

TABLE 1. SELECTED CHEMICAL ANALYSES OF ULTRAMAFIC, AND FELSIC VOLCANIC ROCKS AND ACID PORPHYRY INTRUSIVES. SWAZILAND SEQUENCE, BARBERTON MOUNTAIN LAND, AND ANCIENT GNEISS COMPLEX, SWAZILAND

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1
O_2	44.72	41.61	52.73	52.22	47.37	52.13	51.12	53.12	78.44	70.50	49.86	49.95	50.07	57.68	63.23	57.71	49.34	51.
O_2	0.52	0.31	0.85	0.56	0.46	1.09	0.17	0.78	0.54	0.26	0.70	0.69	1.22	2.57	0.45	0.57	1.49	1.
$_2O_3$	3.25	2.70	9.83	5.42	6.79	13.33	5.92	14.00	15.52	14.50	14.25	13.48	13.34	19.20	15.33	13.73	17.04	16.
$_2O_3$	6.02	5.63	1.23	0.98	1.18	2.24	2.88	0.89	0.41	0.49	2.65	1.82	2.31	0.90	1.91	1.78	1.99	2.
O	5.52	4.35	9.70	8.88	8.08	9.94	5.68	9.60	0.68	1.33	7.67	7.89	9.10	1.72	2.42	3.28	6.82	7.
nO	0.19	0.17	0.22	0.22	0.19	0.21	0.14	0.16	0.01	0.04	0.17	0.18	0.19	0.06	0.08	0.11	0.17	0.
gO	25.35	30.58	10.10	15.25	20.39	6.35	20.28	7.51	0.38	1.28	7.32	9.68	6.10	1.29	2.41	3.87	7.19	5.
aO	6.97	4.29	9.99	12.83	8.31	8.98	9.65	7.27	0.29	1.68	10.69	9.52	9.47	3.98	3.08	4.88	11.72	9.
a_2O	0.49	0.15	2.65	1.21	0.39	2.97	1.04	2.72	0.49	6.29	2.54	2.38	3.34	5.03	4.58	5.08	2.73	2.
$_2O$	0.05	0.03	0.46	0.09	0.06	0.26	0.19	0.39	2.33	1.24	0.16	0.77	0.54	3.50	4.48	3.29	0.16	0.
$_2O+$	5.58	8.81	1.93	2.05	5.26	1.97	1.78	1.87	1.31	0.99	2.70	2.80	2.95	2.36	0.93	0.65	0.69	0.
$_2O-$	0.21	0.22	0.16	0.09	0.25	0.11	0.06	0.09	0.21	0.09	0.11	0.09	0.06	0.32	0.18	—	0.58	—
O_5	—	0.02	0.06	0.05	0.05	0.07	—	0.39	0.14	0.11	0.05	0.09	—	0.31	—	0.24	0.16	0.
O_2	0.26	—	0.14	0.17	—	0.07	—	—	—	1.45	0.48	0.13	0.23	1.73	0.99	3.36	—	—
. of alyses	3	8	3	5	4	4	2	2	1	2	5	5	2	1	1	1	10	94

1. Metaperidotite (peridotitic komatiite), Sandspruit formation.
2. Peridotitic komatiite, Komati formation.
3. Basaltic komatiite (Barberton Type), Komati formation.
4. Basaltic komatiite (Badplaas Type), lower ultramafic unit.
5. Basaltic komatiite (Geluk Type), lower ultramafic unit.
6. Meta-tholeiitic basalt, lower ultramafic unit.
   Columns 1–6: best available analyses of basaltic and peridotitic komatiites and tholeiitic basalts from the lower ultramafic unit of the Onverwacht Group, Barberton Mountain Land (Viljoen & Viljoen 1969*a*).
7. Tremolite rock interlayered with diopside-plagioclase granulite. Ancient gneiss complex, Swaziland (Hunter 1970).
8. Plagioclase amphibolite. Ancient gneiss complex, Swaziland (Hunter 1970).
9. Siliceous aluminous schist (altered tuffaceous sediment) interlayered with metabasalts in lower ultramafic unit – Jamestown schist belt, Barberton Mountain Land. SiO_2, Al_2O_3, Fe_2O_3, Na_2O and K_2O averages based on seven determinations (Anhaeusser 1969, 1971*a*).
10. Felspar porphyry intrusive into Komati formation (Viljoen & Viljoen 1969*a*). Na_2O and K_2O based, in addition on three determinations by Viljoen & Viljoen (1969*a*) and four determinations by Anhaeusser (1971*a*).
11. Pillowed tholeiite. Hooggenoeg formation (Viljoen & Viljoen 1969*b*).
12. Mg-rich metabasalts. Hooggenoeg formation (Viljoen & Viljoen 1969*b*).
13. Tholeiitic basalt. Kromberg formation, mafic-to-felsic unit (Viljoen & Viljoen (1969*b*).
14. Pillowed acid lava, Kromberg formation (Viljoen & Viljoen 1969*b*).
15. Porphyry intrusive into Hooggenoeg formation (Viljoen & Viljoen 1969*b*).
16. Trachyandesite. Fig Tree group (Visser *et al.* 1956).
17. Oceanic tholeiitic basalt (Engel *et al.* 1965).
18. Continental tholeiitic basalt (Manson 1967).

1970*b*). Soda-rich quartz-felspar porphyry intrusive bodies also occur in the lower ultramafic unit and differ in composition (notably the alkalis) from similar intrusive bodies located in the mafic-to-felsic formations (see table 1).

Conformably overlying the predominantly volcanic successions of the Onverwacht group is an assemblage of rocks comprised mainly of detrital sediments with subordinate volcanic and pyroclastic members. This succession has been subdivided into an *argillaceous sedimentary unit* known as the Fig Tree group, and an *arenaceous sedimentary unit* referred to as the Moodies group.

The rocks comprising the Fig Tree group consist mainly of pelitic sediments (greywackes, shales) with siliceous chemical precipitates (banded ferruginous cherts) and minor trachyandesitic lavas (see table 1), agglomerates and tuffs, which together attain thicknesses of between 2100 and 2600 m. The Fig Tree group has recently been subdivided into three formations (Reimer 1967; Condie *et al.* 1970 – see also figure 1).

The Moodies group follows, in places conformably, and in others unconformably, on the underlying Fig Tree assemblages. The succession, which attains thicknesses approaching 3900 m (Visser *et al.* 1956), has its most complete development in the Eureka Syncline (see figure 1) where the Clutha (≈ 1600 m), Joe's Luck (≈ 740 m) and Baviaanskop formations (≈ 686 m) represent a cyclically repetitive assemblage composed predominantly of conglomerates, quartzites, sub-greywackes, sandstones and shales, together with minor volcanic horizons, jaspilite, and banded iron formations (Anhaeusser 1969).

(ii) *The granites*

The Barberton Mountain Land comprises a strongly deformed, predominantly northeasterly trending synclinal remnant enveloped by a variety of intrusive granitic rocks. A number of narrow, arcuate, tapering schist belts protrude from the main body of the greenstone belt and are the direct result of the intrusion of numerous early diapiric granites, the latter prising apart the successions, stoping and assimilating much of the lower Onverwacht stratigraphy, and imposing a distinctive structural imprint on the adjacent formations. A complex structural history involving several periods of superimposed folding can be directly ascribed to the emplacement of various granite bodies throughout the evolution of the greenstone belt (Ramsay 1963; Anhaeusser 1969, 1971*a*, *d*; Viljoen & Viljoen 1969*f*). The structural deformation coupled with the granite intrusions produced the low-grade regional greenschist metamorphism which predominates throughout the greenstone belt. Amphibolite facies rocks are confined to areas immediately adjacent to granite and pegmatite intrusive contacts.

In the Transvaal the term ancient tonalitic gneisses is used in a broad sense to include a wide variety of biotite- and hornblende-bearing tonalitic granites and gneisses grading locally into trondhjemitic, dioritic, granodioritic and quartz-dioritic equivalents and including a variety of metamorphic rocks derived principally from a mafic and/or ultramafic primary source (Anhaeusser 1971*b*; Viljoen & Viljoen 1969*f*). Also included within this category of granites, but not restricted to them, are the diapiric plutons which intrude the Swaziland Sequence in the Barberton Mountain Land. In this region the diapiric plutons are among the oldest granites and range in age between 3200 and 3400 Ma (see figure 2 and table 3). Structurally, the diapiric plutons possess foliated, often lineated margins, and contain alined xenoliths and fragments of the greenstone belt. Away from the contacts the gneissic texture can be absent or only weakly developed and the granites may be relatively homogeneous. The diapiric granite-gneisses characteristically range in composition from hornblende tonalites (the Kaap Valley granite, see figure 2) to leucobiotite tonalite/trondhjemite gneisses (Anhaeusser 1969, 1971*a*; Viljoen & Viljoen 1969*c*). A distinctive feature of these granites, and illustrated in table 2, is their soda-rich character. Also listed in table 2 are examples of similar hornblende and biotite bearing tonalites and trondhjemitic gneisses from the Johannesburg–Pretoria granite dome in the central Transvaal (Anhaeusser 1971*b*), and from the ancient gneiss complex in Swaziland (Hunter 1971). The overall similarities in texture, petrology, and chemistry between the Transvaal tonalitic gneisses and those in Swaziland is striking. However, because of the absence of gneissic doming and the slightly lower alkali contents of the

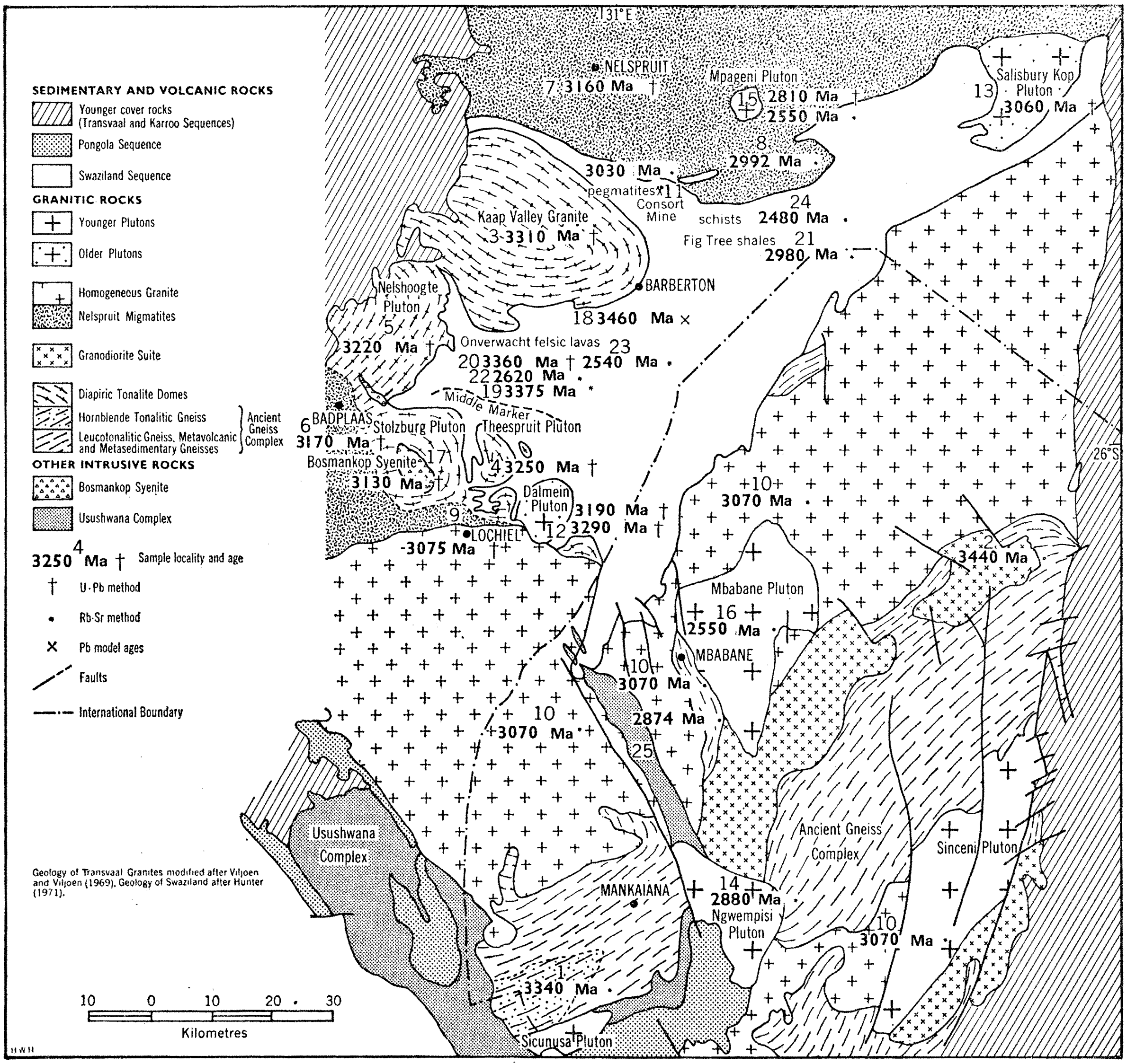

Figure 2. Simplified geological map of the eastern Transvaal and Swaziland showing the various granitic rock-types surrounding the Barberton Mountain Land together with their respective age measurements. In addition, the localities of the more important age determinations carried out in the Barberton greenstone belt itself are illustrated. Further geochronological details are to be found in table 3.

Swaziland tonalites, when compared with those in the Barberton area, Hunter (1971) has classified them into the ancient gneiss complex. The validity of this argument is questionable since the tonalitic gneisses on the Johannesburg–Pretoria dome have alkali contents comparable with those of Swaziland, yet their behaviour with respect to the Swaziland Sequence remnants on the dome is similar to that recorded in the Barberton area. Due, however, to indifferent exposure on the dome no obvious diapirism is evident.

In addition to the ancient tonalitic gneisses, the granites in the eastern Transvaal and Swaziland have been subdivided into categories which reflect a wide range of compositional, textural, and field relationships. To the north of the Barberton greenstone belt the Nelspruit Granite terrain consists of a complex assemblage of gneisses, migmatites, homogeneous and nebulitic granodiorites, adamellites, and pegmatites (Visser *et al.* 1956; Anhaeusser 1966, 1969,

Table 2. Selected chemical analyses of Archaean granitic rocks from Swaziland and the eastern and central Transvaal

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	71.16	65.44	61.79	64.84	70.96	67.57	67.67	71.26	72.21	72.83	72.70	70.42	71.20
TiO_2	0.34	0.42	0.54	0.49	0.18	0.37	0.49	0.37	0.25	0.23	0.30	0.35	0.25
Al_2O_3	14.84	15.23	15.94	15.44	14.93	16.45	15.92	14.46	14.39	13.83	14.24	14.79	13.73
Fe_2O_3	0.77	0.98	1.47	1.80	0.79	0.79	1.09	1.39	0.66	0.85	0.55	0.88	1.16
FeO	1.52	3.33	3.46	2.44	1.04	2.06	2.20	0.80	1.33	1.31	1.22	1.38	1.81
MnO	0.02	0.08	0.10	0.04	0.05	0.06	0.05	0.04	0.03	0.11	0.05	0.05	0.10
MgO	0.95	3.20	3.50	2.60	0.78	1.30	1.29	0.84	0.60	0.54	0.39	0.91	0.77
CaO	3.18	4.69	5.50	4.25	2.32	3.62	3.58	1.80	1.58	1.23	1.53	1.81	1.83
Na_2O	4.82	4.38	3.96	4.93	5.38	5.04	4.58	4.65	4.37	3.46	4.31	4.65	3.38
K_2O	1.65	1.57	1.79	1.53	1.92	1.44	2.10	3.55	3.57	5.08	3.99	3.61	5.10
H_2O+	0.75	0.96	1.65	0.90	0.56	0.95	0.98	0.67	0.58	0.63	0.63	0.70	0.11
H_2O-	0.07	0.09	0.07	0.20	0.13	0.06	0.50	0.08	0.16	0.08	0.05	0.13	0.62
P_2O_5	0.12	0.13	0.27	0.18	0.06	0.10	0.17	0.13	0.10	0.16	0.10	0.14	0.07
CO_2	—	—	0.12	—	—	—	—	—	0.43	—	0.08	—	—
no. of analyses	6	2	3	4	3	4	6	1	3	12	5	3	4

1. Tonalitic gneiss. Ancient gneiss complex, Swaziland (Hunter 1971).
2. Hornblende tonalitic gneiss. Ancient gneiss complex, Swaziland (Hunter 1971).
3. Hornblende/biotite tonalitic gneiss. Johannesburg–Pretoria dome (Anhaeusser 1971*b*).
4. Kaap Valley Granite hornblende tonalitic gneiss, Barberton District. Na_2O and K_2O based on seven determinations (Anhaeusser 1971*a*).
5. Stolzburg, Nelshoogte, and Theespruit diapiric plutons, Barberton Mountain Land. Biotite tonalite/trondhjemite gneiss (Viljoen & Viljoen 1969*c*).
6. Biotite tonalite/trondhjemite gneiss, Johannesburg–Pretoria dome. Average of samples RK2, SK5, LP2, and SB7 (Anhaeusser 1971*b*).
7. Leucocratic tonalite (trondhjemitic). Granodiorite suite, Swaziland (Hunter 1971).
8. Mliba granodiorite, Granodiorite suite, Swaziland (Hunter 1971).
9. Nelspruit migmatites and gneiss, Transvaal. Na_2O and K_2O based on ten determinations (Viljoen & Viljoen 1969*c*).
10. Homogeneous granite, Swaziland. Average of homogenized granite and varieties containing gneiss relics (Hunter 1971).
11. Homogeneous to porphyritic granodiorite – adamellite suite Johannesburg–Pretoria dome (Anhaeusser 1971*b*).
12. Older granite plutons. Salisbury Kop and Dalmein plutons, Barberton Mountain Land (Viljoen & Viljoen 1969*c*).
13. Younger granite plutons. Average of Mpageni granite (Visser & Verwoerd 1960), and 3 Swaziland granite plutons (Hunter 1971).

1971*a*; Viljoen & Viljoen 1969*c*). This complex migmatite terrain is considered by some to be possibly representative of an original basement, although ages (3160 to 2990 Ma) consistently younger than the diapiric granites are obtained (see figure 2 and table 3). Migmatites and gneisses similar to those in the Nelspruit terrain also occur in parts of Swaziland (Hunter 1971) and in areas southwest of the Barberton greenstone belt.

Grading upwards into higher ground, and forming part of the Lochiel plateau and the Transvaal and Swaziland highveld, is the homogeneous hood granite (Viljoen & Viljoen 1969*f*; Hunter 1971). Described as potash-rich, homogeneous granites, veined by a complex stockwork of pegmatites, these rocks have yielded consistent ages of 3070 Ma in Swaziland (see figure 2 and table 3). Geochemical data relating to the Nelspruit migmatites and gneisses, the homogeneous hood granite in Swaziland, and the homogeneous granodiorites and adamellites from the Johannesburg–Pretoria dome are listed in table 2.

The last granitic event in the eastern Transvaal and Swaziland resulted in the emplacement of a number of medium- to very coarse-grained, often conspicuously porphyritic, granite plutons with sharply defined contacts. Two ages of pluton emplacement, decided on the basis

TABLE 3. A SUMMARY OF AGE MEASUREMENTS IN THE BARBERTON MOUNTAIN LAND AND SWAZILAND

).	field unit and description*	method	age (Ma) [primary ^{87}Sr/^{86}Sr]	reference
1	Ancient gneiss complex, Mankaiana area, Swaziland. Hornblende tonalitic gneisses	Rb–Sr	3340	Allsopp *et al.* (1969)
2	Granodiorite Suite, Swaziland. Granodioritic gneisses and migmatite	Rb–Sr	3440 ± 300	Allsopp *et al.* (1962)
3	Kaap Valley granite. Hornblende tonalitic gneiss	U–Pb	3310 ± 40	Oosthuyzen (1970)
4	Theespruit pluton, Tjakastad area. Biotite tonalitic gneiss	U–Pb	3250 ± 40	Oosthuyzen (1970)
5	Nelshoogte pluton. Biotite tonalite/trondhjemite gneiss	U–Pb	3220 ± 40	Oosthuyzen (1970)
6	Lekkerloop Spruit. Gneisses and migmatites	U–Pb	3170 ± 20	Oosthuyzen (1970)
7	Nelspruit town area. Granite gneiss, migmatites	U–Pb	3160 ± 50	Oosthuyzen (1970)
8	Nelspruit gneisses and migmatites north of Consort Gold Mine	Rb–Sr	2992 ± 70 [0.7052 ± 0.0019]	de Gasparis (1967)
9	Lochiel area. Gneisses and migmatites	U–Pb	3075 ± 100	Oosthuyzen (1970)
0	Homogeneous granodiorites (Old G4 of Swaziland)	Rb–Sr	3070 ± 60	Allsopp *et al* (1962)
1	Consort Gold Mine. Pegmatites intrusive into Swaziland Sequence	Rb–Sr	3030 ± 40 [0.766 ± 0.061]	Allsopp *et al.* (1968)
2	Dalmein pluton. Coarse-grained porphyritic granodiorite	U–Pb	sphene – 3190 ± 70 apatite – 3290 ± 80	Oosthuyzen (1970)
3	Salisburykop pluton. Coarse-grained granodiorite	U–Pb	3060 ± 30	Oosthuyzen (1970)
4	Ngwempisi pluton Swaziland. Coarse-grained granite	Rb–Sr	2880 ± 340	Allsopp *et al.* (1962)
5	Mpageni pluton. Coarse-grained granite	U–Pb	zircon – 2810 ± 80 apatite – 2810 ± 80	Oosthuyzen (1970)
		Rb–Sr	2550 ± 90 [0.7065 ± 0.0016]	de Gasparis (1967)
6	Mbabane pluton Swaziland. (Old G5, coarse-grained granite)	Rb–Sr	2550 ± 70	Allsopp *et al.* (1962)
7	Bosmanskop syenite pluton. Medium and coarse-grained syenite	U–Pb	3130 ± 30	Oosthuyzen (1970)
8	Galena from gold mines in the Swaziland Sequence	Pb model age	3460	Ulrych *et al.* (1967)
9	Middle marker. Laminated sediments in Onverwacht group. Swaziland Sequence	Rb–Sr	3375 ± 20 [0.7016 ± 0.0005]	Hurley *et al.* (1972)
0	Hooggenoeg formation. Quartz porphyry (felsic lavas). Onverwacht group, Swaziland Sequence	U–Pb	3360 ± 100	Van Niekerk & Burger (1969
1	Sheba mine area. Fig Tree shales, Swaziland Sequence	Rb–Sr	2980 ± 20 [0.712 ± 0.005]	Allsopp *et al.* (1968)
2	Felsic lavas. Onverwacht group, Swaziland Sequence	Rb–Sr	2620 ± 20 [5 at 0.7000 ± 0.0003] [2 at 0.7027 ± 0.0003] [2 at 0.7058 ± 0.0003]	Allsopp *et al.* (1972)
3	Felsic lavas, Onverwacht group, Swaziland Sequence	Rb–Sr	2540 ± 50 [0.719 ± 0.006]	Allsopp *et al.* (1968)
4	Consort Gold Mine. Biotite–tremolite schists, Swaziland Sequence	Rb–Sr	2480 ± 30 [0.719 ± 0.039]	Allsopp *et al.* (1968)
5	Usushwana complex, Swaziland. Basic differentiated body.	Rb–Sr	2874 ± 30 [0.7029 ± 0.0036]	Davies *et al.* (1969)

* See figure 2 for localities.

of field evidence, are known to occur in Swaziland (Hunter 1971). A twofold grouping, based on geochronological findings, is also possible in the Transvaal where the Salisbury Kop and Dalmein granite plutons and the Bosmanskop syenite pluton give ages in excess of 3000 Ma, while the Mpageni granite is considerably younger (see figure 2 and table 3). The plutons are distinctive by virtue of their topographic expression, texture, lithology, mode of emplacement, and limited metamorphic effects. Characteristically, they give rise to rugged tors or castle koppies and sharply transgress and abruptly truncate structures in older rocks, often without pronounced disturbance (Viljoen & Viljoen 1969*f*; Hunter 1971). A further distinction displayed by the majority of the plutons is a general enrichment in K_2O, this being most noticeable in the younger plutons of Swaziland and with the Mpageni granite (see table 2), as well as with the Bosmanskop syenite body.

Up to now little attention has been given in this paper to the ancient gneiss complex and the granodiorite suite defined by Hunter (1968, 1970, 1971), and adopted in Swaziland. In a recent review of the granitic rocks of the eastern Transvaal and Swaziland, Viljoen & Viljoen (1969*c*, *f*) proposed that much of Hunter's ancient gneiss complex and granodiorite suite should be incorporated within their ancient tonalitic gneiss assemblage, which they postulate, represents a widely generated tonalitic magma derived during a major differentiation episode within the upper mantle, post-dating the Swaziland Sequence. Viljoen & Viljoen suggest that this magma was 'a complementary response to the immediately preceding vast outpouring of largely "primitive" mafic and ultramafic lavas (komatiite), all singularly devoid of alkalis and other lithophile elements'. Many of the metamorphic relics within the Swaziland ancient gneiss complex are also regarded by these authors as being remnants of the basal Swaziland Sequence. The ancient gneiss complex of Swaziland is thus envisaged as consisting of remnants of the basal portion of the Swaziland Sequence intruded by tonalitic magma, the latter being the ancient tonalitic gneisses. The opposing classifications of the Swaziland and eastern Transvaal granites have been tabulated by Hunter (1971) as follows:

Viljoen & Viljoen (1969*f*)	*Hunter* (1971)
D. The young plutons	6. The granite plutons
C. The Nelspruit gneiss and migmatites	5. The homogeneous hood granite
B. The homogeneous hood granite	4. The Nelspruit gneisses and migmatites
A. The ancient tonalitic gneisses	3. The tonalite gneiss domes
	2. The granodiorite suite
	1. The ancient gneiss complex

During subsequent discussion attempts will be made to evaluate the discordant viewpoints outlined above.

The nature of the early crust of the Earth

The problems Earth scientists are confronted with concerning the nature and development of the early crust are fundamental in geology and efforts on a wide front are constantly aimed at resolving these difficulties. Granitic rocks account for the major portion of the exposed crust of southern Africa as well as for most shield areas of the world. From their widespread development and their extremely variable character it is clear that they have played a fundamental role in the evolutionary development of the sialic crust of the continents as we know them today. The questions to be answered and which directly concern the origin of the continents must relate to the granites and their times of emplacement. Were the granitic rocks of the shield areas always present in some form or another from the earliest beginnings or have they developed by later invasion of granitic and granodioritic material beneath certain regions of a primordial mafic crust?

Over the years two opposing schools of thought have emerged, the first suggesting, on the one hand, that continental material was formed very early in the history of the Earth by rapid separation of the Earth into core, mantle and crust while the other major viewpoint suggests that continents have grown throughout geological time as derivatives of the mantle as it undergoes partial melting, differentiation, and degassing processes. The primordial crust has variously been described as having originally been of sialic composition by such students of

Earth history as Vening Meinesz (1950), Poldervaart (1955), and Ramberg (1964), to name but a few. Some of the proponents of a first-formed basaltic or more mafic crust include Lawson (1932), Gill (1961), Wilson (1959) and Dietz (1965). In addition, Engel (1963) has suggested that the North American continent developed by accretion and secular differentiation from basaltic and more mafic crust basing his reasoning on: '(i) the striking analogy between the oldest rock complexes in the Canadian shield and rocks of the island arcs; (ii) the progressive, secular differentiation of igneous and sedimentary rocks in successively formed geologic provinces, from rocks typically oceanic in character to rocks more characteristically continental; (iii) the crudely zonal patterns of successive, major granite forming and related continent-forming events, as manifest in decipherable rock provinces'.

Recent useful reviews of continental and crustal evolution have been provided by Wilson (1967) and Taylor (1967). From these and other studies it is evident that no unequivocal solutions to the enigmatic problems have yet been agreed upon.

Evidence for a primitive sialic crust

According to Sutton (1967) some of the most extensive earliest Precambrian metasediments known on Earth are those from the northeast segment of the Baltic shield in the Kola Peninsula of the U.S.S.R., where a variety of psammitic and pelitic rocks was in existence before metamorphism 3600 to 3200 Ma ago. It was suggested that the source rocks from which these sediments were derived might approach 4000 Ma in age, although it was believed that no relics of crust over 3600 Ma would be encountered because of extensive reworking during this early period of earth history. More recently, isotopic dating of very early Precambrian amphibolite facies gneisses from the Godthåb District of West Greenland gave a Rb–Sr whole-rock isochron age of 3980 ± 170 Ma† and isotope data with an initial $^{87}\mathrm{Sr}/^{86}\mathrm{Sr}$ ratio of 0.6992 ± 0.0010. In addition, a Pb–Pb whole-rock isochron age of 3620 ± 100 Ma was also obtained (Black *et al.* 1971). These data appear to provide the first direct evidence for the existence of some granitic crust very early in the Earth's history.

(i) *The Barberton Mountain Land*

Very ancient sedimentary successions are also present in the southern African greenstone belts, where they constitute the greater portions of the Shamvaian group in Rhodesia and the Fig Tree and Moodies groups in the Barberton Mountain Land. No absolute ages can yet be ascribed to the latter sedimentary groups but they are clearly older than the Kaap Valley granite dated at 3310 ± 40 Ma (Oosthuyzen 1970). This diapiric pluton is responsible for much of the complex structural disturbance found in the area north of Barberton, including the folding and flattening of the Fig Tree and Moodies sediments preserved in the Eureka and Ulundi synclines (Anhaeusser 1969). The Fig Tree and later sediments also overly upper Onverwacht acid volcanic rocks dated at about 3400 Ma (Van Niekerk & Burger 1969). This suggests that the base of the Fig Tree has an age of approximately 3350 Ma.

No reliable evidence concerning the pre-Swaziland Sequence basement has yet been obtained from the granitic rocks of the region so that indirect evidence relating to the possible nature of the early crust must come largely from the rocks contained in the Barberton greenstone belt itself. With these aims in mind the earliest recognizable detrital sediments in the area, namely,

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† At the Royal Society meeting, S. Moorbath (Department of Geology, University of Oxford) reported that the most recent information indicated a Rb–Sr age of 3760 Ma.

the Fig Tree sediments, were examined recently by Condie *et al.* (1970) who concluded, from studies of the petrology and geochemistry of the greywackes, that the source area from which these rocks were derived was of diverse composition; chert, volcanic, and granite-metamorphic source materials (microcline, quartz, granitic rock fragments) being most prevalent. Much of the material comprising the Fig Tree sediments appears to have been derived from contemporary volcanic activity as well as from Onverwacht or Onverwacht-like volcanics. Immature greywacke textures indicate that weathering of source materials was not pronounced and that the original greywacke detritus was not transported great distances prior to deposition and burial.

It is useful to dwell further on the findings of Condie *et al.* (1970) as these will provide a background to the discussions which follow. Particularly noteworthy are the secular compositional trends displayed by the greywackes with stratigraphic height. In the sediments of the Sheba Formation from the Ulundi Syncline, notable decreases in volcanic rock fragments, Ti, Zr, Na, and the Na/K ratio, as well as increases in granitic and metamorphic rock fragments, Ca, Sr, K, Ba and Rb occur stratigraphically upwards. The amount of granitic detritus continues to increase upwards in the Fig Tree and overlying Moodies group sediments where, in the Stolzburg Syncline, granitic pebbles compose up to 2.5 % of the lower Moodies conglomerates (Reimer 1967).

The similarity in composition of most greywackes to Ca-rich granite (tonalite–trondhjemite–quartz diorite–granodiorite) has been discussed by Condie (1967), and Winkler (1967). Condie *et al.* (1970) demonstrated that the Fig Tree greywackes, when compared to most other greywackes and Ca-rich granite, are enriched in Mg and Ni and, in the case of the greywackes of the lower Fig Tree, are depleted in Al, Na and K. Anomalously high Ni and Cr contents of the Fig Tree shales (495 and 860 parts/10^6 respectively) were also reported (Danchin 1967). These data imply that the early sediments were derived from a provenance area containing significant amounts of ultramafic material. Such a source might conceivably have been the lower ultramafic unit of the Onverwacht group, the latter invaded by early tonalitic granites. To Condie *et al.* (1970) the progressive increase in sialic detritus appeared to represent the gradual unroofing of a granitic-metamorphic terrain and these authors suggested that the sediments may have derived from the ancient gneiss complex in Swaziland. The secular compositional variations that can be demonstrated with increasing stratigraphic height in the Fig Tree can, however, be interpreted in more than one way. Undoubtedly granitic rock-types were available in the source area of the sediments. However, whether these were present prior to Fig Tree times or whether they developed contemporaneously with the sediments by secular processes of granitic addition is a matter for debate.

Granitic rocks contributed to the arenaceous sedimentary unit comprising the Moodies group. The basal conglomerate of the Clutha Formation contains numerous pebbles of undoubted granitic composition (Visser *et al.* 1956; Anhaeusser 1966, 1969). Graphic quartz-felspar intergrowth textures characterize the granitic pebbles found in the Eureka syncline and distinguish them from any known granites in the area. Chemical analyses show these pebbles to be enriched in potash (Anhaeusser 1969), and Van Niekerk (1967) has reported an age of 4100 Ma for a pebble from the Moodies basal conglomerate. However, confirmation of this old age has yet to be carried out. Initial findings suggest that the textures seen in the pebbles are primary, but the possibility cannot be discounted that they have undergone transformation during deformation and regional metamorphism. Various degrees of sericitization of the plagioclase felspars may account for the high potash values recorded.

The polymictic basal conglomerate of the Moodies group also contains pebbles of quartz and felspar porphyry identical to the intrusive porphyry bodies found in the Komati Formation of the Onverwacht group but the origin of quartzitic pebbles remains obscure. The overlying Moodies arenaceous sediments comprise quartzofelspathic sandstones and quartzites and contain abundant K-felspar and other minerals derived from a granitic source.

(ii) *The ancient gneiss complex, Swaziland*

Brief mention has already been made of the suite of metamorphic rocks in Swaziland regarded by Hunter (1970) as predating the Swaziland Sequence. As with the pre-Sebakwian rocks of Rhodesia much of the ancient gneiss complex consists of resister rocks such as amphibolites, and ultramafic rocks (see chemical analyses, table 1). In addition, diopside–plagioclase granulites, ironstones, and a variety of biotite-rich gneisses occur scattered throughout the middleveld regions of Swaziland. In the Mkhondo valley a large variety of rock-types have been recorded. These include quartzites and quartzofelspathic gneisses, cummingtonite–anthophyllite–cordierite gneisses, cordierite and garnetiferous gneisses, quartz–biotite–hornblende–diopside gneisses, and tonalitic gneisses. Many of the quartzites and quartzofelspathic gneisses are of sedimentary origin but are exceptionally rare, being restricted in their development to a few localities that have only limited areal extent. At one of the larger outcrop localities of this type, which is restricted to a single prominent hill in the Mkhondo valley, quartzites occur interlayered with kinzigites, mica schist, banded ironstones and taconites, as well as small pebble conglomeratic-grit beds. A broad zone of plagioclase amphibolites separates the layered succession from a zone of migmatitic gneisses.

The amphibolites and ultramafic rocks of the ancient gneiss complex are regarded by Hunter (1970) as being originally of volcanic origin. Migmatization of the amphibolites have, in places, produced banded rocks in which narrow felsic layers alternate with bands of amphibolite, with the amphibole adjacent to the felsic component marginally altered to biotite. Intimately associated with the mafic-ultramafic xenolithic remnants are the widespread hornblende and biotite tonalitic gneisses discussed earlier (see also table 2). Geochronological studies carried out by Allsopp, Davies, de Gasparis & Nicolaysen (1969) and R. D. Davies (manuscript in preparation) on the hornblende tonalitic gneisses from the Mankaiana area (see figure 2) have yielded Rb–Sr isochron ages of 3340 Ma and represent some of the oldest rocks yet dated in southern Africa.

Despite these and many other facts and observations, including a structural analysis and information concerning early mafic dykes in the gneisses and migmatites Hunter (1970, p. 147) admits that *there is no direct evidence* to prove that the ancient gneiss complex formed the floor to the Swaziland Sequence. He contends, however, that sufficient circumstantial evidence is available to uphold such a viewpoint. The correlation of the ancient gneiss complex is of considerable importance in reconstructing the early geological history of southern Africa. Even if, as seems to be Hunter's contention, these ancient assemblages do not represent reworked Swaziland Sequence rocks, then there still remains the problem of trying to locate the floor upon which the sedimentary and volcanic rocks of the ancient gneiss complex was deposited. To some the area may appear to qualify for inclusion with the classical assessment of James Hutton who, in his *Theory of the Earth* of 1788, saw in the record of the rocks '...no vestige of a beginning...no prospect of an end'.

(iii) *Rhodesian greenstone belts*

Volcanic rocks together with minor chemical sedimentary horizons (banded ironstones, cherts), constitute the bulk of the Sebakwian and Bulawayan assemblages which together have similarities to the lower ultramafic unit. The close correspondence of the Onverwacht group of the Swaziland Sequence with the Sebakwian and Bulawayan rocks has been outlined by Viljoen & Viljoen (1969*e*). There is, however, no clear distinction between the sediments of the Bulawayan and the overlying Shamvaian group and there has been a tendency lately, whether justifiably or not, to regard all sediments overlying the thick volcanic successions as belonging to the Shamvaian group (Bliss & Stidolph 1969). As the Shamvaian has a narrow lower argillaceous unit and an upper more arenaceous assemblage it has been equated broadly with the Fig Tree and Moodies groups (Anhaeusser *et al.* 1969; Viljoen & Viljoen 1969*e*). Bliss & Stidolph (1969), aware of the correlation difficulties currently prevailing, viewed the problem objectively and classed the Rhodesian greenstone belt sediments into four major associations; the banded ironstones; the quartz mica schists; the phyllites; and the conglomerate–grit associations, the last-mentioned assemblage generally being regarded as the youngest.

The polymictic conglomerates contain numerous granite pebbles and the clastic sediments demonstrate clearly that they were derived from a heterogeneous source terrain, including one of a granitic or metamorphic nature. In the Shabani area of Rhodesia, there is evidence in the field of sediments, at present classed with the Bulawayan group, directly overlying a peneplained floor of tonalitic gneiss (Morrison & Wilson 1971). These exposures are viewed by many as providing conclusive evidence for the existence of a granitic crust in pre-greenstone belt times. The rocks at this contact, however, include conglomerates, grits, argillites, banded ironstones, and limestones. *No* volcanic rocks directly overlie the gneisses and therefore all that can justifiably be concluded from the exposures is the fact that the sediments are younger than the granites.

(iv) *Pre-Sebakwian rocks in Rhodesia*

Rocks regarded as older than the Sebakwian group have been recognized in Rhodesia by Stowe (1968*a*, *b*). Remnants of banded ironstones and of mafic and ultramafic rocks occur strewn throughout the gneisses southwest of Selukwe. These rocks, together with the associated migmatites, were metamorphosed to the pyroxene granulite facies† before suffering retrograde metamorphism. The remnants outcrop close to Sebakwian group rocks in both the Selukwe and Ghoko schist belts which are metamorphosed to only the greenschist or epidote–amphibolite facies, of metamorphism. This, coupled with the fact that, in places, the Sebakwian rocks retain their original textures led Stowe (1968*b*) to conclude that they were younger than those of the higher grade. Before retrograde metamorphism, the rocks regarded as pre-Sebakwian in age were the high-grade metamorphic equivalents of banded ironstones and basaltic and ultramafic magnesium-rich rocks. These rocks now consist, respectively, of coarse-grained quartz–magnetite and hornblende–andesine granulites as well as fine-grained hornfelsic rocks, and occur as relics in their retrograde equivalents comprised of actinolite–chlorite or biotite schists and tremolite–penninite or talc schists. The granulites and their derived schists are associated with

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† At the Royal Society meeting, J. F. Wilson (University College of Salisbury, Rhodesia) reported that many of the rocks considered to be of granulite grade, appear to be localized, occurring in close proximity to late intrusive dykes.

banded migmatites and are also always foliated parallel to the migmatite trends. Both have undergone polyphase folding.

Although the arguments presented by Stowe (1968*a*, *b*) for the existence of a pre-Sebakwian basement complex have met with widespread approval, both the writer and M. J. Viljoen & R. P. Viljoen (personal communication) have reservations concerning the interpretations that have been made and consider that most, if not all, of the supposed pre-Sebakwian rocks represent remnants of the lowermost members of the greenstone belt stratigraphy. Extensive invasion by granites is held responsible for the migmatization of xenoliths and for the complex metamorphic history of the area. Rapid variations in metamorphic grade, from greenschist facies to amphibolite facies can, for example, be demonstrated in the Barberton Mountain Land (Anhaeusser 1969, 1971*a*, 1972; Viljoen 1964; Viljoen & Viljoen 1969*a*, *d*) as well as in greenstone occurrences elsewhere in the world. Telescoped metamorphic aureoles of this kind are known, according to Buddington (1959) and Engel (1968), from studies of much more recent geological environments, to be products of granite invading and enveloping near-surface parts of the crust.

Evidence for a primitive simatic crust

To Dietz (1965) the advent of the cold accretion model for the Earth, combined with the secondary origin of sial by mantle differentiation, heralded a new definition for the term *original crust* – its composition would be ultramafic and chrondritic rather than sialic. This original crust, it might furthermore be supposed, could have been completely destroyed during convective processes and subsequent geochemical fractionation leading to the concentration of the lithophile elements in the outer zones of the Earth. However, not all of this primordial crust need necessarily have vanished and it is the contention of many investigators working in the shield areas of the globe that vestiges of this crust have remained intact in some of the deeply infolded greenstone belt depositories.

Recently, some of the oldest granitic gneisses yet recorded in North America were reported in the vicinities of Morton and Montevideo in the Minnesota River Valley. Yielding Rb–Sr whole-rock isochron ages of 3550 Ma (Goldich, Hedge & Stern 1970) the gneisses are considered to have formed by synkinematic intrusions of trondhjemitic and granitic magmas into country rocks which appear to have been a layered series of basaltic lavas, possible sill-like masses of diabase or gabbro, peridotite, and mica schists of sedimentary origin. In the Yellowknife subprovince of the western Canadian shield Green & Baadsgaard (1971) have also concluded that the Yellowknife volcanics, having calc-alkaline affinities, were poured out 2650 Ma ago on a thin oceanic-type crust. They could find no isotopic evidence for contamination of the volcanics by extensive early Archaean sialic segments. Additional support for the existence of an early mafic or ultramafic crust has been provided by Lawson (1932), Wilson (1959), Engel (1963, 1968), Gill (1961), Folinsbee, Baadsgaard, Cumming & Green (1968), Glikson (1970, 1971), Viljoen & Viljoen (1970*a*), Anhaeusser (1971*b*) and many others. As most of the more recent evidence relates to the geochemical and isotopic properties of the rocks from the ancient granite–greenstone terrains this aspect will be dealt with in the following section which attempts to relate the Barberton greenstone belt to an original oceanic-type setting.

The Barberton greenstone belt – a primitive island arc?

The earliest model formulated for the Barberton greenstone belt 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 *et al.* 1968). Continued studies resulted in revised models being erected (Anhaeusser *et al.* 1969; Viljoen & Viljoen 1969*e*) which avoided direct comparisons with younger geological features and events, particularly the Alpine-type orogenic belts.

The term 'geosyncline' has frequently been used elsewhere in the world to describe early Precambrian greenstone occurrences, but it appears that the strongest modern-day analogue lies with the island arcs. Engel (1968) contended that the Onverwacht assemblages, considered separately, had analogies in parts of the Kuril and Aleutian islands where crustal thicknesses are approximately 12 to 18 km (Goryatchev 1962; Coats 1962), while the Swaziland Sequence, taken as a whole, appeared analogous to parts of the Phillipines, New Caledonia, Kamchatka, and some Caribbean islands, these regions having crustal thicknesses ranging from 15 to 25 km (Officer, Ewings, Edwards & Johnson 1957).

A direct comparison has also been made by Folinsbee *et al.* (1968) of the early Precambrian greenstone occurrences in the Yellowknife area of the Canadian Slave Province and more recent island arcs. The early Yellowknife volcanism commenced with outpourings of a thick sequence of tholeiitic basalts and terminated with thinner successions of quartz latites and dacites. Intruded into the volcanic sequences are a variety of granitic rocks ranging from quartz diorite to granodiorite and granite. These authors found considerable similarity between the Yellowknife occurrences and the fossa magna of the Japanese island arc described by Matsuda (1962). Not only is the volume of tholeiitic and other magma in the Slave Province of the same order of magnitude as that of the fossa magna, but it is also clearly demonstrable that the thick sequences of volcanic rocks in the Japanese islands were followed by diorite intrusion and greywacke-type sedimentation. Markhinin (1968) came to similar conclusions when he took the opposite approach of equating the Kuril island arc with 'ancient geosynclinal structures'. He also considered that these areas marked the birthplace of continental crust which formed at the expense of oceanic crust while also contributing simultaneously to the formation of the Earth's hydrosphere and atmosphere.

The simple comparisons, based on lithologies and rock associations in greenstone belts and island arcs, have been supplemented by an ever increasing amount of geochemical data from the two environments as well as from a growing knowledge of the deeper oceanic areas of the Earth. In the Barberton region the peridotitic and basaltic komatiites and tholeiitic rocks from the lower ultramafic unit have no known parallel except possibly in the material being dredged from the abyssal regions of the oceans. Rocks of the mafic-to-felsic unit, with calc-alkaline affinities, also possess chemical attributes which make comparisons with anything but island arc or oceanic-type volcanism difficult. Jakeš & Gill (1970) have assembled considerable major and trace element chemical data from volcanic rocks found in oceanic settings and group the information to define three rock series, namely, the abyssal tholeiite series, the island arc tholeiite series, and the calc-alkaline series. Trace element data from the Barberton area is not yet available so that the comparisons, made in table 4, are restricted to only a few major elements, with the Na_2O/K_2O ratio values being most diagnostic. Comparisons are made between the various basaltic rock-types of the Onverwacht group and those of average Canadian and Western Australian greenstone belts as well as rocks from oceanic and continental environments. It is significant that all the greenstone belt examples are grouped in the island arc or abyssal tholeiite series with the basaltic komatiites, in particular, demonstrating values even more primitive than those found today in abyssal oceanic settings. The relatively low Al and Ti levels of the ancient oceanic basaltic rocks (see table 4) indicate, furthermore, that the melts could not have originated or equilibrated at depths greater than 15 km, provided the oceanic thermal gradient and the *g* value in the early Precambrian did not differ considerably from those of the present (Glikson 1971; Green & Ringwood 1967). Additional geochemical data from the early Precambrian terrains of Canada and Western Australia have been evaluated by Glikson (1971), whose conclusions support the general comparison here being made between the ancient basalts and calc-alkaline volcanics and the more recent oceanic equivalents. The ancient basalts, however, apart from the lower Al and Ti, tend to have higher concentrations of Mn, Ni, Cr, Co, Rb and Fe/Fe + Mg (total iron as FeO). The ancient calc-alkaline rocks, on the other hand, fall into the range between oceanic tholeiites and island arc tholeiites with respect to their low K contents. They also have lower Al and Ti, and higher Fe/Fe + Mg (total iron as FeO), Rb, and Ba, than recent oceanic tholeiites.

TABLE 4. COMPARISON OF SOME MAJOR ELEMENT GEOCHEMISTRY OF THE CALC-ALKALINE, ISLAND-ARC THOLEIITE AND ABYSSAL THOLEIITE SERIES WITH THAT OF CONTINENTAL THOLEIITES AND BASALTS FROM EARLY PRECAMBRIAN GREENSTONE BELTS

	calc-alkaline series†	island arc tholeiitic series†	abyssal tholeiitic series†
SiO_2 range %	53–70	45–70	47–62
mode %	59	53	49
TiO_2%	0.5–1.2	0.5–1.5	1.0–2.5
Al_2O_3%	16–19	14–19	14–19
Na_2O/K_2O	2–3	4–6	10–15

	continental tholeiites‡	Canadian greenstone metabasalts§	Western Australian greenstone metabasalts‖
SiO_2%	51.5	49.5	51.4
TiO_2%	1.2	1.0	1.0
Al_2O_3%	16.3	14.9	14.3
Na_2O/K_2O	2.9	6.6	13.9

	Barberton Mountain Land–Onverwacht group					
	basaltic komatiites from lower ultramafic unit¶		tholeiitic basalts from lower ultramafic unit††		tholeiitic basalts from mafic to felsic unit‡‡	
	range	mean	range	mean	range	mean
SiO_2%	46–58	51.0	49–54	52.1	48–52	49.9
TiO_2%	0.3–1.4	0.6	0.8–1.6	1.1	0.6–1.2	0.9
Al_2O_3%	4–12	7.4	12.9–14.2	13.3	12.7–15.3	13.5
Na_2O/K_2O	7–53	16.7	7–23	11.0	2.4–55.0	12.6

† Data compiled by Jakeš & Gill (1970).
‡ Average of 946 analyses given by Manson (1967).
§ Average of 325 analyses compiled from Baragar & Goodwin (1969). Data from the Canadian Shield.
‖ Average of 103 analyses compiled from Glikson (1971). Data from the Western Australian Shield.
¶ Data compiled from 22 analyses listed by Viljoen & Viljoen (1969*a*).
†† Data compiled from four analyses listed by Viljoen & Viljoen (1969*a*).
‡‡ Data compiled from nine analyses listed by Viljoen & Viljoen (1969*b*).

Additional information of significance concerns recent Sr isotopic studies of ultramafic, mafic and felsic volcanic rocks from the Onverwacht group carried out by Allsopp, Viljoen & Viljoen (1972). The number of samples analysed are far too few for any form of uniqueness to be claimed from the data, but the low initial ratios obtained (see table 3, no. 22) are considered meaningful. Primary $^{87}Sr/^{86}Sr$ values (R_0) as low as 0.700 lends support to the identification of the samples with primitive abyssal tholeiites (mean R_0 values of $\sim$ 0.703). The variations in the R_0 values from the Onverwacht lavas are consistent with similar changes that are known to occur in samples taken across island arcs. R_0 values from samples on the seaward side are significantly lower than the values obtained from the continental side (Ozima, Zushu & Ueno 1971). These changes are presumably related to the zonal arrangements of lava types that also occur across island arcs described by Jakeš & White (1969) and Jakeš & Gill (1970). Data of the type outlined above is constantly being made available and considerable advances must result in the future. What information there is at present, however, makes it difficult to argue against an oceanic or island arc-like original setting for the development of many of the earliest Precambrian volcanic successions, including the Onverwacht assemblages.

Early Precambrian crustal evolution in southern Africa – a model

In the foregoing sections evidence has been presented which attempts to summarize objectively the most pertinent features and arguments that relate to early Precambrian crustal development in southern Africa. Because of the similarities that exist between the oldest rocks of the shield areas of the world findings relevant to the discussion have been heavily drawn upon from elsewhere to supplement the local findings. There now remains the task of trying to reconcile, where possible, the contrasting or opposing points of view with respect to the nature of the primitive crust. Popular opinion still tends to favour the existence of a primordial sialic crust but an increasing amount of evidence in support of the opposite viewpoint is being made available.

Of particular significance recently has been the recognition of the suite of mafic and ultramafic rocks, classed as the lower ultramafic unit, and which possess a clearly unique geochemistry. The only justifiable comparisons to this rock assemblage are found in present-day abyssal or oceanic settings or at the base of geosynclinal piles. Primitive sediments, almost exclusively of chemical or volcanogenic origin, occur with the volcanic rocks but are volumetrically insignificant. Although these rock types appear to be preserved only in deeply infolded greenstone belts they are envisaged as having once extended over widespread areas where they represented oceanic crust. This widespread development can be seen and inferred from the regional distribution of such rocks in the shield areas where innumerable relics, ranging in size from major greenstone belts to smaller xenolithic rafts and shredded schistose slivers, occur scattered within the granites. In southern Africa this relationship is best displayed on the Rhodesian craton, stripped of its cover sequences (see figure 3). The ages of these lower volcanic assemblages are unknown because of insuperable geochronological difficulties attendant upon dating rocks of this type. All that can be said concerning their ages is that they are older than the granites intruding them. *Nowhere* can it be demonstrated that they overlie granitic crust.

The progressive chemical changes that can be traced from the base of the stratigraphy upwards was probably a response to secular changes occurring with mantle differentiation. This culminated, in the lower ultramafic unit, with the emplacement of the early sodic porphyry bodies which heralded the development of the Na-rich granites. The middle marker in the Barberton greenstone belt, which has been dated at 3375 ± 20 Ma by Hurley, Pinson, Nagy & Teska (1972) comprises the first prominent sedimentary horizon, also made up almost exclusively of chemical precipitates and volcanogenic debris. Conceivably this unit could have

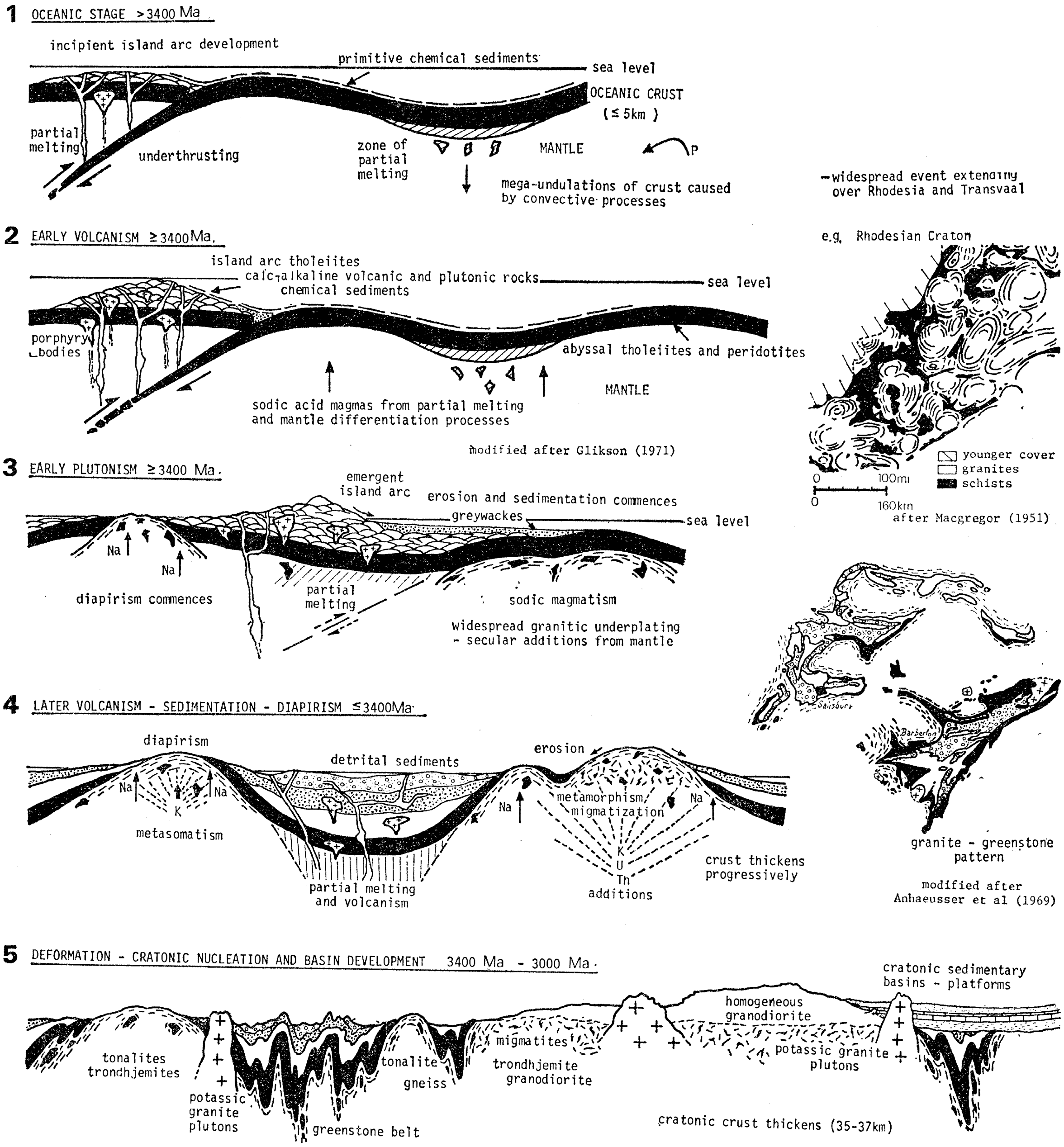

Figure 3. Schematic cross-sectional sketches illustrating the progressive stages of early Precambrian crustal development in southern Africa. Processes involving partial melting and granite underplating result in successive stages of transformation of a primary oceanic crust into regions having island arc-like characteristics, the latter finally nucleating to form stable cratons or shield areas.

represented the ocean floor for some period, during which time geotectonic processes may have been such as to produce zones of partial melting and incipient island arc-type development. This, coupled with the mantle differentiation processes, resulted in sialic underplating and consequent crustal thickening, Sharply contrasting volcanism followed as a response to these changing conditions and island arc tholeiites and calc-alkaline magmas typical of the mafic-to-felsic unit originated. Calc-alkaline porphyry plutonic additions accompanied the extrusive equivalents (see figure 3), and chemical and volcanogenic sediments increased proportionally to the volume of felsic and pyroclastic volcanicity. Load pressures assisted in the development of a subsiding trough, while island arc emergence, coupled with incipient granitic diapirism, contributed for the first time to the development of detrital sedimentation. The origin of the early sodic granites and porphyry bodies as well as the volcanic rocks with their distinguishing spatial, temporal, and chemical characteristics may be explained by mixing of the partial melting products of resorbed lithosphere and overlying upper mantle as well as by processes involving secular addition of lithophile elements from the mantle. Green & Ringwood (1968) have demonstrated that sodic acid liquids are produced by low degrees of partial melting of amphibolite under wet conditions, within depths of 30 to 40 km. Verhoogen *et al.* (1970-p. 703) also consider that 'from an originally basaltic crust weathering, metamorphism, and partial fusion could form an upper crust of granodioritic composition, and a lower crust consisting of amphibolite somewhat less siliceous than the original basalt'. As Glikson (1971) has pointed out, the extremely high Na/K ratios of the early granites and porphyries distinguished them from common anatectic granites, and they may inherit their characteristics from the extremely low K contents of the primitive oceanic crust.

During the processes of secular granite addition and emplacement the early widespread oceanic crust, in regions away from the downsagging island arc-like areas underwent progressive stages of fragmentation, metamorphism and migmatization. These changes commenced with the influx of trondhjemitic or tonalitic liquids and the ensuing migmatization and transformational processes were assisted by increased K, U and Th additions from the mantle. The processes involved herein emerge as one of the least understood aspects of early Precambrian geology. The telescoped nature of the metamorphic aureoles around greenstone relics has already been mentioned. Differential metamorphic and metasomatic pulses were probably responsible for the complexity we see today. The fact that high-grade metamorphites occur in juxtaposition with low-grade equivalents does not, it is contended, necessarily imply vastly differing ages between the metamorphic assemblages. Hunter (1970) has also shown in Swaziland that migmatization of amphibolites results in the production of banded rocks, and amphiboles transform to biotites. Such processes could conceivably produce the banded gneisses and migmatites so commonly encountered on the crystalline shields, and like those at the spectacular Gwenoro Dam locality in Rhodesia, which Stowe (1968*a*, *b*) and others, consider to be of pre-Sebakwian age. Space does not permit the argument to be further elaborated, but the discussion at this stage might be terminated by quoting, from Wilson (1968, p. 26), a statement referring to a part of Rhodesia but which is virtually applicable to all ancient granitic crustal regions with regard to its message. The statement reads as follows: 'Generally, the banded gneisses are best developed in those areas where remnants of the Sebakwian System are widespread'. This, to the writer, implies that these gneisses and many others like them have developed by progressive transformation of an earlier simatic host.

The earliest noteworthy detrital sedimentation of the type found in the Fig Tree group is also similar to that found associated with island arcs and is characterized by thick greywacke, type accumulations eroded from volcanic rocks as well as from a granitic source. The chemical evolution of these sediments has been discussed. The earliest sediments, it was shown (Condie *et al.* 1970), contain lesser quantities of granitic source material than later sediments in the same pile, an additional factor indicating the progressive availability of such rocks as the granites evolved and as the island arc underwent transformation into portion of a protocontinent. During the sedimentation the depository underwent continued downsagging on the still relatively thin and unstable crust and great thicknesses of sedimentary material accumulated.

The great thicknesses, a characteristic of greenstone belts (Anhaeusser *et al.* 1969), indicate accumulation in deeply subsiding basins or troughs which, combined with the nature of the rock-types, have modern-day equivalents mainly in deep ocean trenches flanking island arcs or in geosynclines.

Sedimentation into Moodies or late Shamvaian times continued to show the effects of progressive granite development with successive stages of tonalite/trondhjemite invasion, and migmatization and homogenization taking place. The deeply infolded greenstone successions underwent several stages of superimposed folding commencing, initially, with gravity induced slumping and faulting and being augmented by deformation accompanying diapiric granite intrusion. The latter event was responsible for the characteristic 'granite–greenstone pattern' displayed on many shield areas (see figure 3).

Still further changes followed, particularly with regard to the granites. Varying spatial and temporal subcrustal additions of granitic fluids continued to permeate the protocontinental nuclei resulting in continued, yet selective processes of rheomorphism, anatexis, granitization and metasomatism, and giving rise to the development of progressively K-enriched granitic phases (granodiorites, adamellites, granites) culminating with the widespread development of homogeneous granites approximately 3000 Ma ago. By this stage the proto-continental crust had stabilized sufficiently for the earliest cratonic sedimentary basins to form (see figure 3). The first of these appears to have been the Pongola Sequence which straddles Swaziland and parts of Natal and the Transvaal (see figure 4). This sequence of sedimentary and volcanic rocks was deposited during the waning phases of granitic activity and was intruded and metamorphosed by granites classed with both the homogeneous hood variety and the younger granite plutons (Roering 1968; Hunter 1971). Although the Moodies/Shamvaian sedimentary assemblages also show features typical of cratonic-type sedimentation (Anhaeusser 1969, 1971*c*), they differ fundamentally from the relatively flat-lying Pongola Sequence in that they were deeply infolded and refolded by deformational events rarely repeated in post-greenstone belt times.

In concluding this part of the discussion cognizance has to be taken of findings, such as those of the ~ 4000 Ma old granites in West Greenland and also, possibly, to parts of the ancient gneiss complex in Swaziland. The existence of an ancient granitic relic such as the one in West Greenland does not necessarily implicate the entire Earth's crust in a similar set of circumstances during this period of time. Just as today there are continents and oceans so too might this have been the case in the past. The conditions in West Greenland do not therefore detract in any way from the conclusions drawn here for the crustal history of southern Africa.

If the arguments relating the Barberton and other greenstone belts to island arc and oceanic settings are upheld, then it is difficult to imagine that a sialic crustal assemblage like that of the ancient gneiss complex could exist immediately adjacent to such a major depositional site as that in which the Swaziland Sequence was laid down. To resolve this enigmatic impasse we might have to call upon plate tectonics in the early Precambrian for assistance. The ancient gneiss complex may just have been fortunate enough to have survived resorption at the site of possibly the Earth's most ancient fossil subduction zone.

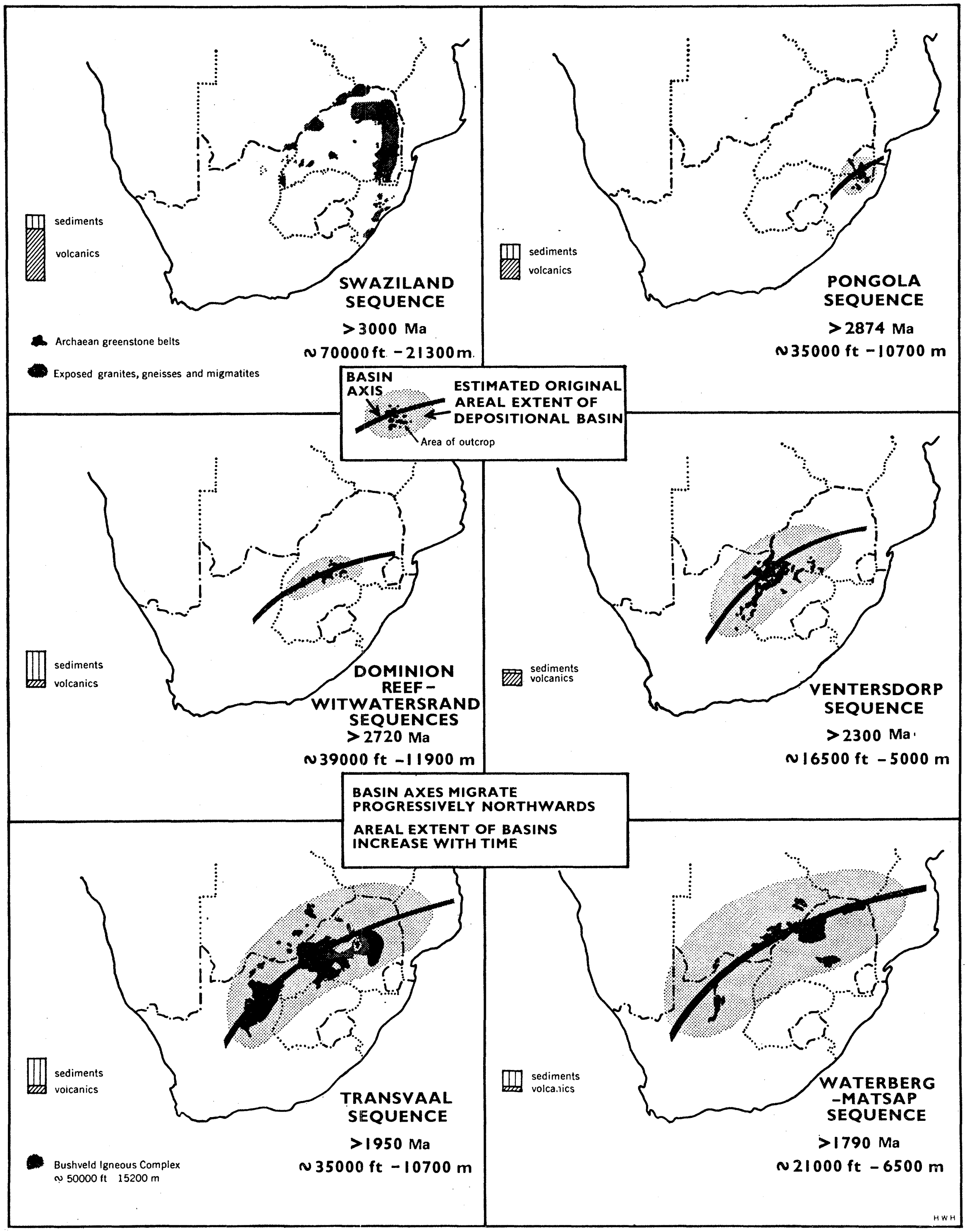

FIGURE 4. Generalized geological maps depicting the progressive development of interior or cratonic basins from early Archaean to middle Proterozoic times in South Africa. Crustal thickening and stabilization results in increased areal extent of each successive stratigraphic sequence, and migrating basin axes might reflect processes akin to accretion. Changes in the ratios of volcanic to sedimentary rocks with time are illustrated by means of bar diagrams.

3. Late Archaean–early Proterozoic crustal development

Following the greenstone belt episode with its associated crystalline basement development, strongly contrasting geological circumstances dominated the crustal evolution of the African subcontinent. The conditions which followed were a direct result of progressive crustal thickening processes following the nucleation and aggregation of the protocontinental fragments discussed previously. The secular granite additions, believed to be largely mantle derived, caused initial thickening from approximately 5 to 7 km in the primordial oceanic setting to intermediate thicknesses of between 12 and 25 km in island arc times. Following this the crust stabilized to thicknesses of between 35 and 37 km on the Kaapvaal craton (Green & Bloch 1969). During late Archaean times (~ 3000 Ma) and extending through to middle Proterozoic times (~ 1600 Ma) the progressive stabilization of the crust can be followed indirectly by examining the thicknesses and areal extent of the developing interior or cratonic basins. To demonstrate this relationship a series of schematic diagrams are presented (see figure 4) which show the areas of outcrop of the major rock sequences falling into the time span being discussed.

Table 5. Age measurements of early Precambrian sequences on the Kaapvaal Craton, South Africa

unit and how dated	method	age (Ma)	reference
Swaziland Sequence			
Sedimentary and volcanic rock ages, sulphide ages, and intrusive granite and pegmatite ages. Barberton and Swaziland	Rb–Sr U–Pb U–Pb	> 3375 ± 20 > 3310 ± 40 > 3360 ± 100	Hurley *et al.* (1972) Oosthuyzen (1970) Van Niekerk & Burger (1969) Ulrych *et al.* (1967)
		> 3460	(see table 3 for details)
Pongola Sequence			
Age measurements on Usushwana Complex which intrudes Pongola rocks. Mhlambanyati area, Swaziland	Rb–Sr	> 2870 ± 30	Davies *et al.* (1969)
Granites intrusive into Pongola rocks, Mahlangatsha and Hlatikulu areas, Swaziland	U–Pb Rb–Sr	> 3050 > 3070 ± 60	Roering (1968) Allsopp *et al.* (1962)
Dominion Reef Sequence			
Overlies granite which sets an upper limit on the age of the sequence. Western Transvaal	Rb–Sr	⩽ 2820 ± 55	Allsopp (1964)
Witwatersrand Sequence			
Overlies granite which sets an upper limit on the age of the sequence. Western Transvaal	Rb–Sr	⩽ 2720 ± 100	Allsopp (1964)
Ventersdorp Sequence			
Age measurements on zircons in quartz porphyry high up in Ventersdorp Sequence. Western Transvaal	U–Pb	⩾ 2300 ± 100	Van Niekerk & Burger (1964)
Transvaal Sequence			
Age measurements on micas, monazites, and zircons in rocks of the Bushveld igneous complex which intrudes the Transvaal assemblage	Rb–Sr	> 1950 ± 150	Nicolaysen *et al.* (1958)
Age measurements on zircons from Bushveld granite	U–Th–Pb	> 2050 ± 60	Burger *et al.* (1967)
Waterberg Sequence			
Ages on zircons in porphyritic granophyric granite intrusive into Waterberg sandstones. Rust de Winter area	U–Pb	> 1790 ± 70	Oosthuyzen & Burger (1964)

Table 6. Southern African crustal development – changes with time

	early Archaean ($\sim$ 3400 Ma)	late Archaean ($\sim$ 3000–1600 Ma) Proterozoic
crust	Mainly oceanic with primitive island-arc-like centres nucleating to form protocontinental masses. Possibly some thin, unstable, primordial granitic crustal segments	Progressively thickened and stabilized protocontinental masses nucleated by addition of mantle-derived sialic constituents and welded together to form cratons and large continental blocks
approximate crustal thickness	$\leqslant$ present-day oceanic crustal thicknesses ($\sim$ 5–7 km) increasing in areas of island-arc-type development to intermediate thicknesses of $\sim$ 12–25 km	Gradual thickening from $\sim$ 20 km to present-day crustal thickness of between 35 and 37 km on the Kaapvaal craton.
volcanic rock-types	Sequential primitive peridotitic and basaltic komatiites, abyssal and island-arc-type tholeiitic basalts, and calc-alkaline to mildly alkalic volcanic and pyroclastic phases. Rapid, cyclical alternations of magma types with stratigraphic height. Volcanism generally K_2O deficient	Extensive, thick, non-sequential, chemically diverse volcanism, including continental-type tholeiitic basalts, andesites, trachytes and rhyolites. Progressive enrichment in K_2O evident
sedimentary rock-types	Palagonitic oozes, thin, poorly developed laminated carbonates, chemical precipitates (banded cherts, thin banded iron formations – jaspilite) carbonaceous cherts and shales. Thick greywacke-shale successions, immature polymictic conglomerates, quartzites, sub-greywackes, sandstones and grits. Sediments derived from rapid erosion and deposited in unstable active environments. Sediments both volcanogenic and quartzofelspathic in origin	Extensive, thick units of conglomerates, orthoquartzites, arkoses, sandstones, shales, dolomite and limestone, chert, and banded and granular iron formations.
type of depository	Restricted, linear to sublinear areas of progressive downsagging in unstable environments.	Extensive, broad cratonic basins and flat lying stable platforms. Sites of accumulation show temporal increase in size (basin dimensions presumably controlled by progressive crustal thickening processes), with northwes migrating basin axes.
type of deformation	Early, linear, gravity induced sagging and slumping producing deeply infolded, isoclinal structures. Diapiric granite emplacement results in increasing structural complexity, and is responsible for poly-deformational tectonism (isoclinal folding and faulting)	Broad areas of long-continued relative tectonic stability. Domes and arches develop and basin subsidence produced by epeirogenic tectonism. Cratonic negative elements comprise interior, yoked, and marginal basins, bordered by shelf areas. Broad-scale regional folding and basin edge faulting
granites and igneous complexes	Early, extensive introduction of mantle derived, potash deficient trondhjemitic, tonalitic, quartz dioritic and granodioritic magmas, causing partial or total assimilation of pre-existing assemblages. Metamorphic, K-metasomatic and palingenetic processes produce migmatites and gneisses. Crustal stability increases progressively by granitic additions	Less extensive granitic influx manifest on craton surface, as thickening by underplating proceeds. Areas still affected by rheomorphism, granitization, anatexis and metasomatism. Local magmatic granite intrusion (granodiorites, adamellites, granites – reflect K_2O enrichment). Massive, basic differented bodies emplaced on stable cratons (e.g. Bushveld, Rooiwater, Usushwana). Extensive mafic dyke invasion
early life forms	Simple, ill-defined, possibly biogenic organisms in carbonaceous cherts and shales. Isolated stromatolites, e.g. Bulawayan dolomitic limestone, Rhodesia	Stromatolites more extensively developed and established. Reported from Ventersdorp and Transvaal Sequences. Biogenic organisms in carbonaceous shales and cherts

Also depicted are the estimated depositional boundaries and basin axes of the individual sequences. From the earliest rocks in the Swaziland Sequence, which occur studded in the crystalline basement, through the Pongola Sequence to the Waterberg–Matsap assemblages, a progressive size increase in the depositional basins is apparent. Also noticeable is a subtle change in the proportion of volcanic to sedimentary rocks, with the older Pongola, Dominion Reef, and Ventersdorp Sequences (see table 5) having proportionally greater volcanic components than the later predominantly sedimentary accumulations. The increasing areal extent of the basins with time is interpreted as being directly proportional to the continuing crustal stability while the northwesterly migrating basin axes might be a reflection of some form of continental accretion about an early Archaean nucleus.

As crustal growth proceeded strong contrasts emerged between the events in the early Archaean and those that occurred in later Archaean and early Proterozoic times. This pattern of events in southern Africa is duplicated to a considerable extent in the Canadian shield (Goodwin 1968*a*, *b*). Broad basins containing flat-lying or gently dipping strata predominate. Lithological differences become marked as the sediments include a high proportion of stable platform types such as orthoquartzite, conglomerate and sandstone, limestone and dolomite, and cherty and granular iron formations. Associated volcanic rocks include thick, extensive, nonsequential varieties embracing continental flood basalts of tholeiitic type as well as andesites, trachytes and rhyolites. Structurally, the deeply infolded, largely gravity induced, deformational characteristics of the early greenstone belts seldom recur on the cratons and relatively mild warping, doming and epeirogenic subsidence, accompanied mainly by faulting and dyke invasion, vecome dominant features of the younger environment. Metamorphism plays a subordinate role on the cratons except where major disturbances occur like those which accompanied the emplacement of the Bushveld and other complexes. Metamorphism is most intense around craton margins and in the high-grade metamorphic mobile belts. The more noteworthy differences that occur time sequentially on the cratons are summarized in table 6.

4. Summary and conclusions

The main facets of southern African early Precambrian crustal evolution are summarized in figures 3 and 4, and in table 6.

(1) The lower ultramafic unit of the Transvaal and Rhodesian greenstone belts is thought to have represented a primordial oceanic-type crust. Geochemical and isotopic data suggests that there is no evidence for contamination of the mafic and ultramafic volcanic assemblages by an earlier extensive sialic crust. The age of this thin (~ 5 to 7 km) primordial crust is unknown but is considered to be well in excess of 3400 Ma old.

(2) The mafic-to-felsic unit assemblages demonstrate characteristics analogous to modern-day island arcs. This is reflected in the distinctive chemical affinities which these rocks possess with respect to island arc tholeiites and the calc-alkaline magma suite.

(3) Incipient granite development resulted from partial melting of the primitive lithosphere and gave rise to the early Na-rich porphyry bodies which, in turn, became calc-alkaline in character as island arc-like development commenced and the crust thickened (≈ 12 to 18 km).

(4) The earliest sedimentary rocks comprised mainly chemical precipitates (banded iron formations, cherts, minor carbonates) as well as volcanogenic debris (tuffs, agglomerates). Incipient detrital sedimentation resulted from island arc emergence and from erosion of

developing granites, gneisses and migmatites. Greywacke-shale sediments containing anomalously high amounts of Ni, Cr and Mg underwent notable chemical and lithological changes stratigraphically upwards. Volcanic detritus shows an upward decrease at the expense of material from a granitic source, suggesting progressive availability of a sialic crustal component. The argillaceous sedimentary unit gave way to the arenaceous sedimentary unit.

(5) The primitive granites invaded the primordial crust causing its fragmentation and migmatization. Initial Na-rich trondhjemite/tonalite liquids were generated as a response to partial melting of the lithosphere coupled with additions derived from mantle differentiation.

(6) Secular granitic additions caused metamorphism, migmatization, rheomorphism, anatexis, and metasomatic transformation of greenstone relics. The evolution of the granitic rocks was accompanied by a progressive introduction of elements such as U, Th, and Rb, with K in particular, being added in increasing amounts. Granitic rocks ranging in composition from trondhjemites, tonalites, and quartz diorites, to granodiorites, adamellites, granites and syenites developed, and heterogeneous phases underwent progressive stages of transformation and homogenization.

(7) Protocontinental segments evolved in the waning phases of island arc-like development. Crustal thickening continued and protocontinental segments aggregated to produce the thick, stable, cratons ($\approx$ 20 to 37 km).

(8) Deeply infolded, sublinear Archaean depositories were superseded in late Archaean and early Proterozoic times by extensive stable platforms and interior or cratonic-type sedimentary basins, the latter generally displaying only mild folding, faulting and regional metamorphism.

(9) Archaean volcanic activity (predominantly oceanic to island arc tholeiitic, and calc-alkaline sequential) changed to chemically diverse, non-sequential, predominantly continental-type volcanism, and immature primitive sediments were superseded by more mature varieties with shelf areas stabilized sufficiently to allow the development of limestone and dolomite formations.

In brief, the development of the African sub-continent shows a continued evolution from an oceanic to a continental crustal setting, involving mainly chemical differentiation processes, the latter leading to the production of thicker, more stable crustal fragments which nucleated to form the crystalline shield.

In a review of this type the ideas and findings of a great number of workers have been drawn on extensively and wherever possible reference has been made in the text to the appropriate source. If I have omitted to acknowledge certain people it has been done unintentionally. I am grateful for the advice and critical comment on various aspects of the study offered me by Professor L. O. Nicolaysen, Dr C. Roering and Mr A. Button.

REFERENCES (Anhaeusser)

Allsopp, H. L. 1964 Rubidium/strontium ages from the western Transvaal. *Nature, Lond.* **204**, 361–363.

Allsopp, H. L., Roberts, H. R., Schreiner, G. D. L. & Hunter, D. R. 1962 Rb–Sr age measurements on various Swaziland granites. *J. geophys. Res.* **67**, 5307–5313.

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

Allsopp, H. L., Ulrych, J. J. & Nicolaysen, L. O. 1968 Dating some significant events in the history of the Swaziland System by the Rb–Sr isochron method. *Can. J. Earth. Sci.* **5**, 605–619.

Allsopp, H. L., Viljoen, M. J. & Viljoen, R. P. 1972 Strontium isotopic studies of the mafic and felsic rocks of the Onverwacht Group of the Swaziland Sequence (in the Press).

Anhaeusser, C. R. 1966 Facets of the granitic assemblage on the north-west flank of the Barberton Mountain Land. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg*, no. 32, 27 pp.

Anhaeusser, C. R. 1969 The stratigraphy, structure, and gold mineralization of the Jamestown and Sheba Hills areas of the Barberton Mountain Land. Unpublished Ph.D. thesis, University of the Witwatersrand, Johannesburg.

Annhaeusser, C. R. 1971*a* The geology of the Jamestown Hills area of the Barberton Mountain Land, South Africa. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg.*, no. 64, 44 pp.; 1972 *Trans. geol. Soc. S. Afr.* (in the Press).

Anhaeusser, C. R. 1971*b* The geology and geochemistry of the Archaean granites and gneisses of the Johannesburg–Pretoria dome. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg*, no. 62, 41 pp.; 1972 *Trans. geol. Soc. S. Afr.* (in the Press).

Anhaeusser, C. R. 1971*c* Cyclic volcanicity and sedimentation in the evolutionary development of Archaean greenstone belts of shield areas. *Spec. Publ. geol. Soc. Aust.* **3**, 57–70.

Anhaeusser, C. R. 1971*d* The Barberton Mountain Land, South Africa – a guide to the understanding of the Archaean geology of Western Australia. *Spec. Publ. geol. Soc. Aust.* **3**, 103–119.

Anhaeusser, C. R. 1972 The geology of the Stolzburg layered differentiated ultramafic complex, Barberton Mountain Land, South Africa (manuscript in preparation).

Anhaeusser, C. R., Mason, R., Viljoen, M. J. & Viljoen, R. P. 1969 A reappraisal of some aspects of Precambrian shield geology. *Bull geol. Soc. Am.* **80**, 2175–2200.

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

Baragar, W. R. A. & Goodwin, A. M. 1969 Archaean volcanism in the Canadian shield. In *Andesite symp.* (ed. A. R. McBirney), **65**, 121. Oregon Department Geol. Min. Indust.

Black, L. P., Gale, N. H., Moorbath, S., Pankhurst, R. J. & McGregor, V. R. 1971 Isotopic dating of very early Precambrian amphibolite facies gneisses from the Godthaab district, West Greenland. *Earth Pl. Sci. Lett.* **12**, 245–259.

Bliss, N. W. & Stidolph, P. A. 1969 A review of the Rhodesian basement complex. *Spec. Publ. geol. Soc. S. Afr.* **2**, 305–333.

Buddington, A. F. 1959 Granite emplacement with special reference to North America. *Bull geol. Soc. Am.* **70**, 671–747.

Burger, A. J., Oosthuyzen, E. J. & Van Niekerk, C. B. 1967 New lead isotopic ages for minerals from granitic rocks, northern and central Transvaal. *Annls Geol. Surv. S. Afr.* **6**, 85–89.

Coats, R. R. 1962 Magma type and crustal structure in the Aleutian arc. In *The crust of the Pacific basin. Geophys. Monograph* **6**, 92–109. American Geophysical Union, Washington, D.C.

Condie, K. C. 1967 Composition of the ancient North American crust. *Science, N.Y.* **155**, 1013–1015.

Condie, K. C., Macke, J. E. & Reimer, T. O. 1970 Petrology and Geochemistry of early Precambrian greywackes from the Fig Tree Group, South Africa. *Bull geol. Soc. Am.* **81**, 2759–2776.

Danchin, R. V. 1967 Chromium and nickel in the Fig Tree shale from South Africa. *Science, N.Y.* **158**, 261–262.

Davies, R. D., Allsopp, H. L., Erlank, A. J. & Manton, W. I. 1969 Sr-isotopic studies on various layered mafic intrusions in Southern Africa. *Spec. Publ. geol. Soc. S. Afr.* **1**, 576–593 (published 1970).

De Gasparis, A. A. A. 1967 Rb–Sr isotopic studies relating to problems of geochronology on the Nelspruit and Mpageni granites. Unpublished M.Sc. thesis, University of the Witwatersrand, Johannesburg.

Dietz, R. S. 1965 Earth's original crust – lost quest? *Tectonophysics* **2**, 515–520.

Engel, A. E. J. 1963 Geologic evolution of North America. *Science, N.Y.* **140**, 143–152.

Engel, A. E. J. 1968 The Barberton Mountain Land: clues to the differentiation of the earth. *Trans. geol. Soc. S. Afr.* **71** (annex), 255–270.

Engel, A. E. J., Engel, C. G. & Havens, R. G. 1965 Chemical characteristics of oceanic basalts and the upper mantle. *Bull. geol. Soc. Am.* **76**, 719–734.

Folinsbee, R. E., Baadsgaard, H., Cumming, G. L. & Green, D. C. 1968 A very ancient island arc. In *The crust and upper mantle of the Pacific area. Geophys. Monograph* **12**, 441–448. American Geophysical Union, Washington, D.C.

Gill, J. E. 1961 The origin of continents. *Trans. R. Soc. Can.* **55**, 103–113.

Glikson, A. Y. 1970 Geosynclinal evolution and geochemical affinities of early Precambrian systems. *Tectonophysics* **9**, 397–433.

Glikson, A. Y. 1971 Primitive Archaean element distribution patterns: chemical evidence and geotectonic significance. *Earth Pl. Sci. Lett.* **12**, 309–320.

Goldich, S. S., Hedge, C. E. & Stern, T. W. 1970 Age of the Morton and Montevideo gneisses and related rocks, southwestern Minnesota. *Bull. geol. Soc. Am.* **81**, 3671–3696.

Goodwin, A. M. 1968*a* Archaean protocontinental growth and early crustal history of the Canadian shield. *23rd Int. Geol. Congr., Prague* **1**, 69–89.

Goodwin, A. M. 1968*b* Evolution of the Canadian shield. *Proc. geol. Ass. Can.* **19**, 1–14.

Goryatchev, A. V. 1962 On the relationship between geotectonic and geophysical phenomena of the Kuril–Kamtchatka folding zone at the junction zone of the Asiatic continent with the Pacific basin: in *The crust of the Pacific basin. Geophys. Monograph* **6**, 41–49. American Geophysical Union, Washington, D.C.

Green, D. C. & Baadsgaard, H. 1971 Temporal evolution and petrogenesis of an Archaean crustal segment at Yellowknife, N.W.T., Canada. *J. Petrol.* **12**, 177–217.

Green, D. H. & Ringwood, A. E. 1967 The genesis of basaltic magmas. *Contr. Miner. Petrol.* **15**, 103–190.

Green, R. W. & Bloch, S. 1969 Recent developments in seismic investigation of crustal and upper mantle structure in South Africa. *Spec. Publ. geol. Soc. S. Afr.* **2**, 477–484.

Green, T. H. & Ringwood, A. E. 1968 Genesis of the calc-alkaline igneous rock suite. *Contr. Miner. Petrol.* **18**, 105–162.

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

Hunter, D. R. 1957 The geology, petrology and classification of the Swaziland granites and gneisses. *Trans. geol. Soc. S. Afr.* **60**, 85–125.

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

Hunter, D. R. 1968 The Precambrian terrain in Swaziland with particular reference to the granite rocks. Unpublished Ph.D. thesis, University of the Witwatersrand, Johannesburg.

Hunter, D. R. 1970 The Ancient Gneiss Complex in Swaziland. *Trans. geol. Soc. S. Afr.* **73**, 107–150.

Hunter, D. R. 1971 The granitic rocks of the Precambrian in Swaziland. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg*, no. 63, 25 pp.; *Trans. geol. Soc. S. Afr.* (in the Press).

Hurley, P. M., Pinson, W. H., Nagy, B. & Teská, T. M. 1972 Ancient age of the Middle Marker horizon, Onverwacht Group, Swaziland Sequence, South Africa. *Earth Planet. Sci. Lett.* **14**, 360–366.

Jakeš, P. & Gill, J. 1970 Rare earth elements and the island arc theoliitic series: *Earth Pl. Sci. Lett.* **9**, 17–28.

Jakeš, P. & White, A. J. R. 1969 Structure of the Melanesian arcs and correlation with distribution of magma types *Tectonophysics* **8**, 223–236.

Lawson, A. C. 1932 Insular arcs, foredeeps and geosynclinal seas of the Asiatic coast. *Bull geol. Soc. Am.* **43**, 353–381.

Macgregor, A. M. 1951 Some milestones in the Precambrian of Southern Rhodesia. *Proc. geol. Soc. S. Afr.* **54**, xxvii–lxxi.

Manson, V. 1967 Geochemistry of basaltic rocks: major elements. In *Basalts: the Poldervaart treatise on rocks of basaltic composition* (eds. H. H. Hess & A. Poldervaart), vol. 1, pp. 215–269. New York: Interscience.

Markhinin, E. K. 1968 Volcanism as an agent of formation of the earth's crust. In The crust and upper mantle of the Pacific area. *Geophys. Monograph* **12**, 413–422. American Geophysical Union, Washington, D.C.

Matsuda, T. 1962 Crustal deformation and igneous activity in the South Fossa Magna, Japan. In The crust of the Pacific basin. *Geophys. Monograph* **6**, 140–150. American Geophysical Union, Washington, D.C.

Morrison, E. R. & Wilson, J. F. 1971 *Excursion guidebook: symposium on the granites, gneisses and related rocks.* Geol. Soc. S. Afr. Rhod. Branch, Salisbury. 44 pp.

Nicolaysen, L. O., De Villiers, J. W. L., Burger, A. J. & Strelow, F. W. E. 1958 New measurements relating to the absolute age of the Transvaal System and of the Bushveld Igneous Complex. *Trans. geol. Soc. S. Afr.* **61**, 137–163.

Officer, C. B., Ewing, J. I., Edwards, R. S. & Johnson, H. R. 1957 Geophysical investigations in the eastern Caribbean–Venezuelan basin, Antilles island arc, and Puerto Rico trench. *Bull. geol. Soc. Am.* **68**, 359–378.

Oosthuyzen, E. J. 1970 The geochronology of a suite of rocks from the granitic terrain surrounding the Barberton Mountain Land. Unpublished Ph.D. thesis, University of the Witwatersrand, Johannesburg.

Oosthuyzen, E. J. & Burger, A. J. 1964 Radiometric dating of intrusives associated with the Waterberg System. *Annls geol. Surv. S. Afr.* **3**, 87–106.

Ozima, M., Zashu, S. & Ueno, N. 1971 K/Rb and Sr^{87}/Sr^{86} ratios of dredged submarine basalts. *Earth Pl. Sci. Lett.* **10**, 239.

Poldervaart, A. 1955 Chemistry of the Earth's crust. *Geol. Soc. Am. Spec. Paper* **62**, 119–144.

Ramberg, H. 1964 A model for the evolution of continents, oceans and orogens. *Tectonophysics* **2**, 159–174.

Ramsay, J. G. 1963 Structural investigations in the Barberton Mountain Land, eastern Transvaal. *Trans. geol. Soc. S. Afr.* **66**, 352–398.

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

Roering, C. 1967 Non-orogenic granites in the Archaean geosyncline of the Barberton Mountain Land. *Inform. Circ. Econ. Geol. Res. Unit. Univ. Witwatersrand, Johannesburg*, no. 35, 13 pp.

Roering, C. 1968 Non-orogenic granites and the age of the Precambrian Pongola Sequence. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg*, no. 46, 20 pp.

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

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

Sutton, J. 1967 The extension of the geological record into the Pre-Cambrian. *Proc. geol. Ass. Lond.* **78**, 493–534.

Swift, W. H. (ed.) 1961 An outline of the geology of Southern Rhodesia. *Bull. geol. Surv. Sth. Rhod.* **50**, 73 pp.

Taylor, S. R. 1967 The origin and growth of continents. *Tectonophysics* **4**, 17–34.

Ulrych, T. J., Burger, A. & Nicolaysen, L. O. 1967 Least radiogenic terrestrial leads. *Earth Pl. Sci. Lett.* **2**, 179–184.

Van Niekerk, C. B. 1967 The suitability of extrusive acid volcanic rocks for U-Pb radiometric dating. Unpublished Ph.D. thesis, University of Cape Town, South Africa.

Van Niekerk, C. B. & Burger, A. J. 1964 The age of the Ventersdorp System. *Annls geol. Surv. S. Afr.* **3**, 75–86.

Van Niekerk, C. B. & Burger, A. J. 1969 A note on the minimum age of the acid lava of the Onverwacht Series of the Swaziland System. *Trans. geol. Soc. S. Afr.* **72**, 9–21.

Vening Meinesz, F. A. 1950 Convection currents in the Earth and the origin of continents. *Proc. K. ned. Akad. Wet.* Ser. B, **55**, 527–554.

Verhoogen, J., Turner, F. J., Weiss, L. E., Wahrhaftig, C. & Fyfe, W. S. 1970 *The Earth. An introduction to physical geology*, 748 pp. New York: Holt, Rinehart & Winston, Inc.

Viljoen, M. J. 1964 The geology of the Lily Syncline and portion of the Eureka Syncline between the Consort Mine and Joe's Luck Siding, Barberton Mountain Land. Unpublished M.Sc. thesis, University of the Witwatersrand, Johannesburg.

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

Viljoen, M. J. & Viljoen, R. P. 1969*b* The geological and geochemical significance of the upper formations of the Onverwacht Group. *Spec. Publ. geol. Soc. S. Afr.* **2**, 113–151.

Viljoen, M. J. & Viljoen, R. P. 1969*c* The geochemical evolution of the granitic rocks of the Barberton region. *Spec. Publ. geol. Soc. S. Afr.* **2**, 189–218.

Viljoen, M. J. & Viljoen, R. P. 1969*d* An introduction to the geology of the Barberton granite-greenstone terrain. *Spec. Publ. Geol. Soc. S. Afr.* **2**, 9–27.

Viljoen, M. J. & Viljoen, R. P. 1969*e* A reappraisal of granite-greenstone terrains of shield areas based on the Barberton model. *Spec. Publ. geol. Soc. S. Afr.* **2**, 245–274.

Viljoen, M. J. & Viljoen, R. P. 1969*f* A proposed new classification of the granitic rocks of the Barberton region. *Spec. Publ. geol. Soc. S. Afr.* **2**, 153–180.

Viljoen, M. J. & Viljoen, R. P. 1970*a* Archaean vulcanicity and continental evolution in the Barberton region, Transvaal. In *African magmatism and tectonics* (ed. T. N. Clifford and I. Gass), pp. 27–39. Edinburgh: Oliver and Boyd.

Viljoen, R. P. & Viljoen, M. J. 1970*b* The geology and geochemistry of the layered ultramafic bodies of the Kaapmuiden area, Barberton Mountain Land. *Spec. Publ. geol. Soc. S. Afr.* **1**, 661–688.

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

Visser, H. N. & Verwoerd, W. J. 1960 The geology of the country north of Nelspruit, explanation of sheet 22 (Nelspruit). *Geol. Surv. S. Afr.*

Wilson, J. F. 1968 Geology of the country around Mashaba. *Bull. geol. Surv. Rhod.* **62**, 239 pp.

Wilson, J. F. 1973 The Rhodesian craton – an essay in cratonic genesis. *Phil. Trans. R. Soc. Lond.* A **273**, 389–411 (this volume).

Wilson, J. T. 1959 The origin of continents and Precambrian history. *Trans. Royal Soc. Can.* **43**, 157–184.

Wilson, J. T. 1967 Theories of building of continents. In *The Earths' mantle* (ed. T. F. Gaskell), pp. 445–473. London: Academic Press.

Winkler, H. G. F. 1967 *Petrogenesis of metamorphic rocks*, 2nd ed., 237 pp. New York: Springer-Verlag.