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MAGMATIC CYCLES AND THE EVOLUTION OF THE ARCHAEAN GRANITIC CRUST IN THE EASTERN TRANSVAAL AND SWAZILAND

by

C. R. ANHAEUSSER
(Deputy Director, Economic Geology Research Unit and Reader in Archaean Geology)

and

L. J. ROBB
(Research Officer, Economic Geology Research Unit)

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ABSTRACT

Three magmatic cycles are recognized in the Archaean granitic crust of the eastern Transvaal and Swaziland in terms of their geochemical, geochronological and field characteristics. The earliest cycle commenced approximately 3 550 m.y. ago and involved the formation of soda-rich tonalites and trondhjemites and a complex series of bimodal gneisses and migmatites. The second cycle began approximately 3 200 m.y. ago with the emplacement of multi-component potash-rich batholiths that enveloped vast areas occupied by the gneisses and migmatites of the earlier magmatic event. The third cycle was initiated with the intrusion of a number of late, mainly potash-rich granite and syenite plutons, approximately 2 900 m.y. ago.

The distinctive physical, chemical and isotopic characteristics of the components of each cycle indicate that the subdivision of the various granitic rocks in the area into three magmatic cycles provides a useful conceptual framework within which to view the evolution of the Archaean crust in the region.

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I. INTRODUCTION

The granitic terrane flanking the Barberton greenstone belt in the eastern Transvaal has been critically re-examined over the past five years as part of South Africa's contribution to the International Geodynamics Programme. The investigations have involved regional as well as detailed field mapping, supplemented by geochemical, geochronological and structural studies, all of which have been undertaken in an attempt to decipher the evolutionary history of the Archaean crust in the area.

Earlier studies in the eastern Transvaal and Swaziland led to the recognition of a wide range of granitic rock types which are portrayed on various maps accompanying attempts aimed at classifying the granitic rocks of the region (Anhaeusser et al., 1968; Hunter, 1957, 1970, 1973, 1979; Viljoen and Viljoen, 1969a, b; Visser et al., 1956). Due to the nature and complexity of the granitic terrane no consensus has yet been achieved on the correlation of these rocks, and there are widely divergent views on the evolution of the primitive crust (Anhaeusser, 1973, 1980a; Condie and Hunter, 1976; Glikson, 1976, 1979; Hunter, 1970, 1973, 1979; Hunter et al., 1978; Viljoen and Viljoen, 1969b).

Experience gained in the Geodynamics study strip in the eastern Transvaal, coupled with reconnaissance investigations in parts of Swaziland, has prompted this reassessment of the granitic terrane. A three-fold subdivision is proposed whereby the various granitic components are grouped together under the general heading of *magmatic cycles*, erected on the basis of similarities in field relations, rock geochemistry and isotopic ages. Each magmatic cycle embraces a wide range of events and granitic rock types with unifying characteristics that formed by processes operating throughout the time span defining the magmatic cycle.

No attempt is made here to fully justify grouping the granitic rocks into the scheme outlined in the following sections : this justification will be made in a fuller publication of results of the Geodynamics research programme (Anhaeusser, Barton and Robb - in preparation).

II. GEOLOGIC SETTING

To the east of the Transvaal Drakensberg escarpment lies the Archaean granite-greenstone terrane of the eastern Transvaal and adjoining territory of Swaziland (Figure 1). Centrally situated with respect to Figure 1 is the Barberton greenstone belt which consists of an assemblage of metamorphosed volcano-sedimentary rocks, including mafic and ultramafic lavas (basaltic and peridotitic komatiites, high-Mg basalts, tholeiites), mafic to felsic volcanics and pyroclastics (calc-alkaline series basalts-dacites-rhyodacites) and sediments (greywackes, shales, banded iron-formations, cherts, quartzites, conglomerates), described, for example, by Anhaeusser (1978), Viljoen and Viljoen (1969c, d) and Visser et al. (1956).

Of particular significance are the numerous greenstone enclaves located in the granitic rocks surrounding the Barberton Mountain Land. Best preserved are the xenolithic remnants in the Badplaas area, which have been traced for over 50 km beyond the southern limits of the main greenstone mass (Anhaeusser and Robb, 1978, and Figure 1). Studies have confirmed the observations of Viljoen and Viljoen (1969c, d) that the scattered greenstone enclaves in the gneisses consist entirely of assemblages characteristic of the lower formations of the Onverwacht Group of the Swaziland succession. Detailed mapping has shown, furthermore, that these enclaves can be traced from the gneissic terrane directly into the Barberton greenstone belt in several areas.

The Barberton volcanic sequences have yielded a precise Sm-Nd age of 3 540 ± 30 m.y. (Hamilton et al., 1979) and all available evidence suggests that these rocks were intruded by tonalites and trondhjemites ranging in age from approximately 3 450 - 2 900 m.y. (Barton, 1980; Oosthuyzen, 1970). Localized zones of migmatite occurring in areas immediately flanking some greenstone enclaves - (e.g. southeast of Badplaas - Anhaeusser and Robb, 1978) are interpreted as forming by the intrusion and interaction of the granitic rocks with the greenstone xenoliths.

Investigations in Swaziland (Jackson, 1979; A.C. Wilson, personal communication, 1979) have revealed numerous greenstone enclaves between the Komati River in the north and Mankaiana in the south (Figure 1). These rocks are similar to the meta-volcanics and meta-sediments of the Onverwacht sequence in the Barberton greenstone belt (Barton et al., 1980; Jackson, 1979). Known locally as the Dwalile metamorphic suite, the successions consist mainly of mafic and ultramafic lavas and subordinate layered intrusions, overlain by chemical and clastic sediments.

The Dwalile supracrustal remnants are enveloped by migmatites and a variety of tonalitic and trondhjemitic orthogneisses and appear to be justifiable grounds for correlating the Mankaiana and Badplaas areas rather than regarding the two environments as having entirely separate origins.

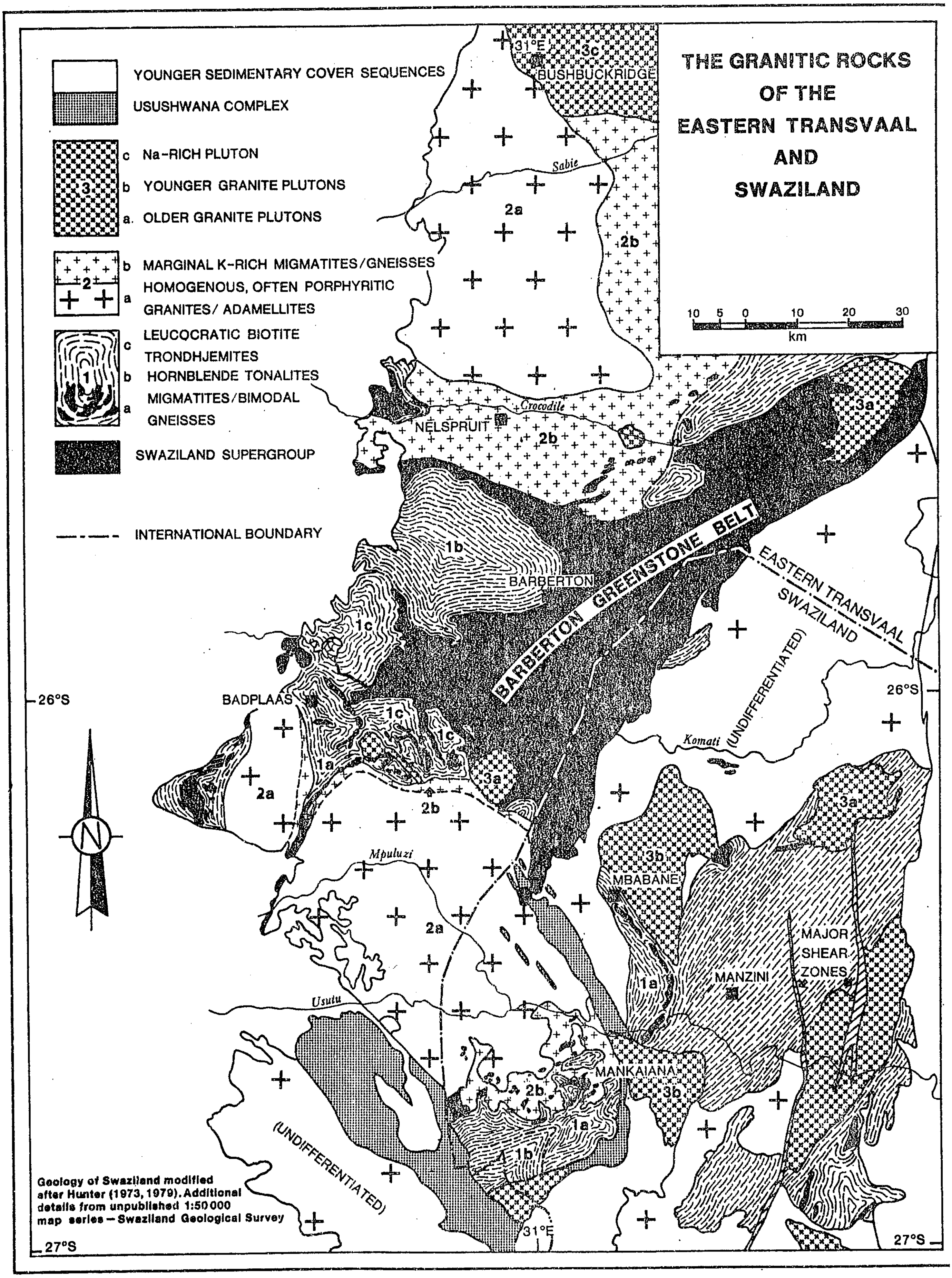

Figure 1 : Simplified geological map of the eastern Transvaal and Swaziland showing a threefold subdivision of the granitic rocks of the region.

A major line of disagreement centres around the nature of the early crust in the Barberton - Swaziland region. One view is that the siliceous low-K leucocratic gneisses (the Bimodal Suite of Hunter, 1974a, and Hunter *et al.*, 1978) predate the Onverwacht Group greenstones and may represent a basement to the latter. The alternative is that orthogneisses and migmatites making up the Ancient Gneiss Complex in Swaziland (the latter comprised of the Bimodal Suite, the homogeneous Tsawela tonalitic gneisses and the Dwalile and Mkhondo metamorphic suites - Barton *et al.*, 1980; Hunter, 1970, 1974a), are younger than the basal units of the Onverwacht Group and were derived by partial melting of an ensimatic source (Anhaeusser, 1973; Viljoen and Viljoen, 1969a).

Rb-Sr isotopic studies by Barton *et al.* (1980) on orthogneisses of the Ancient Gneiss Complex in northeastern Swaziland yield an age of 3555 ± 111 m.y. (2σ) which is indistinguishable from the Sm-Nd age of the lower Onverwacht volcanic rocks. These findings are consistent with the view, favoured here, that the orthogneiss component of the Ancient Gneiss Complex is coeval with, and was possibly derived from, rocks compositionally similar to those of the basal members of the Barberton greenstone belt. The low initial $^{87}Sr/^{86}Sr$ ratio of 0.6999 ± 0.0016 (2σ) reported by Barton *et al.* (1980) further precludes any other significant prehistory for the Swaziland orthogneisses.

In terms of the approach adopted in this paper the $\sim$ 3550 m.y. age represents the derivation or emplacement age and hence, the commencement of granitic magmatic activity of the *first magmatic cycle*. The low initial ratios indicate that the leucocratic gneisses of the Bimodal Suite cannot be a much older basement to the Onverwacht rocks but rather are the partial melt products of ensimatic parents. This type of parental material is abundant in the nearby Barberton greenstone belt and in the related greenstone enclaves in the surrounding granitic terrane.

The *second magmatic cycle* commenced approximately 3200 m.y. ago when K-rich granitic magma was emplaced as large batholithic bodies both north and south of the Barberton greenstone belt (Fig. 1). Linked with this major crust-forming episode were supplementary intrusive phases whose origins appear related to processes responsible for the development of the batholithic magmas.

The potassic batholiths are rimmed by migmatite and gneiss aureoles which reflect zones of interaction between the batholiths and pre-existing crust. Within these zones, which are best developed around the Nelspruit batholith in the north and the Mpuluzi batholith south of the Barberton greenstone belt, the earlier formed Na-rich gneisses, migmatites and greenstone remnants were variably influenced by processes of granitization and metasomatism. All the events ascribed to the second magmatic cycle appear to have terminated approximately 3000 m.y. ago, providing the crustal stabilization necessary for the subsequent development of the early Proterozoic cratonic basins (Anhaeusser, 1973; Hunter, 1974b).

The *third magmatic cycle* began approximately 2900 m.y. ago when numerous discrete granitic and syenitic bodies were emplaced into an already consolidated, tectonically stable, crustal regime. These high level, generally K-rich, plutons are clearly transgressive and cluster into two groups defining a set of Older Plutons (circa 2900 m.y. old) and another of Younger Plutons (circa 2600 m.y. old).

The Usushwana Igneous Complex, dated at approximately 2810 m.y. (Davies *et al.*, 1970 ; age corrected using decay constant 1.42 for ^{87}Rb), overlaps with the third magmatic cycle but as these rocks consist mainly of pyroxenites, gabbros and granophyres they will not be considered further.

Lastly, it is emphasized that the three magmatic cycles are most clearly defined by their distinctive physical (field) and geochemical characteristics supplemented by confirmatory Rb-Sr isotopic data. The earliest event coincided with the onset of sodic igneous activity approximately 3550 m.y. ago. This was followed by potassic igneous activity 3200 m.y. ago and finally by late stage potassic and, to a lesser extent, sodic igneous activity 2900 m.y. ago.

III. FIRST MAGMATIC CYCLE

A. Migmatites and Bimodal Gneisses

Migmatites and/or bimodal gneisses are best developed immediately southwest of the Barberton greenstone belt (Robb, 1980) and in the type-area of the Ancient Gneiss Complex in the Mankaiana district in Swaziland (Jackson, 1979). In both areas, the terrane is underlain dominantly by tonalite or trondhjemite gneisses (column 1, Table 1) intimately associated with subordinate amphibolites together with variable but commonly significant proportions of anatectic material. The migmatites are invariably associated with greenstone supracrustal remnants correlated directly with the Barberton greenstone belt (e.g. in the region southeast of Badplaas - Anhaeusser and Robb, 1978; Anhaeusser, 1980b) or forming part of the Dwalile metamorphic suite in the Mankaiana region. The migmatites in both regions (Fig. 1, see distribution of 1a) have been subjected to repeated deformation so that commonly the relationships between greenstone remnants and gneisses are obscure. Also characteristic of both areas are syn-tectonic mafic dykes which probably represent an intrusive episode that was coeval with the Upper Onverwacht (Geluk Subgroup) (Jackson, 1979; Robb, 1980).

TABLE 1

AVERAGE MAJOR ELEMENT COMPOSITIONS OF GRANITIC ROCKS REPRESENTATIVE OF THE THREE MAGMATIC CYCLES IN THE EASTERN TRANSVAAL AND SWAZILAND

Column	1	2	3	4	5	6	7	8	9	10
Map Reference	1a	1b	1c	2a	2a	2a	2b	3a	3b	3c
SiO_2	71,16	65,05	70,67	69,72	67,70	72,38	67,59	70,42	71,20	68,97
TiO_2	0,34	0,49	0,34	0,32	0,42	0,26	0,32	0,35	0,25	0,36
Al_2O_3	14,84	15,75	15,75	15,52	15,83	13,95	15,59	14,79	13,73	15,80
Fe_2O_3	0,77	4,40*	2,42*	2,18*	2,83*	0,85	2,39*	0,88	1,16	2,52*
FeO	1,52	-	-	-	-	1,40	-	1,38	1,81	-
MnO	0,02	0,06	0,06	0,05	0,05	0,09	0,05	0,05	0,10	0,06
MgO	0,95	2,51	1,11	0,95	1,72	0,51	1,29	0,91	0,77	1,61
CaO	3,18	4,47	3,11	2,92	2,41	1,33	2,29	1,82	1,83	2,72
Na_2O	4,82	5,18	4,25	4,31	4,22	3,76	3,95	4,65	3,38	4,98
K_2O	1,65	1,52	1,55	3,65	3,18	4,67	3,93	3,61	5,10	2,13
P_2O_5	0,12	0,20	0,08	0,04	0,11	0,23	0,08	0,14	0,11	0,01
H_2O^+	0,75	-	-	-	-	0,68	-	0,70	0,62	-
H_2O^-	0,07	-	-	-	-	0,08	-	0,13	0,07	-
LOI†	-	1,01	1,01	0,48	0,59	-	0,55	-	-	0,45
No. of Analyses	6	41	7	18	9	8	9	3	4	9

* Total iron as Fe_2O_3 † Loss on ignition

Columns 1. Siliceous gneisses and migmatites - Bimodal Suite (Hunter, 1973).
2. Hornblende (± biotite) tonalite gneiss - Kaap Valley Pluton (Robb, in preparation).
3. Leuco-biotite trondhjemite gneiss - Rooihoogte Pass Area (Anhaeusser and Robb, 1978).
4. Homogeneous coarse porphyritic granite - Nelspruit Porphyritic Granite (Robb, 1978).
5. Homogeneous medium-grained, grey granodiorite - Hebron Granodiorite (Robb, 1978).
6. Homogeneous, medium-grained, pinkish grey adamellite - Homogeneous Hood Granite (Viljoen and Viljoen, 1969b).
7. Marginal K-rich gneisses and migmatites - Nelspruit Migmatite and Gneiss Terrane (Robb, 1978).
8. Late granite plutons - Older Plutons (Viljoen and Viljoen, 1969b).
9. Late granite plutons - Younger Plutons (Viljoen and Viljoen, 1969b).
10. Na-rich pluton - Cunning Moor Tonalite (Robb, 1978).

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The interpretation of migmatites southwest of the Barberton greenstone belt is markedly different from that for migmatites or bimodal gneisses of the Mankaiana region in spite of the apparent similarities referred to above. In the Badplaas area, three types of migmatite are recognized (Robb, 1980). The first type occurs where tonalite/trondhjemite gneisses intruded and migmatized portions of recognizable greenstone crust. The second type occurs where migmatization results from the intrusion of significant proportions of anatectite and obscures relations between trondhjemite and amphibolite. The third migmatite variety developed where tholeiitic dykes intruded pre-existing tonalite/trondhjemite gneiss and were subsequently deformed and migmatized. No unequivocal relationships point to primitive komatiitic basalts, that are largely correlatable with the lower greenstone successions, post-dating the earliest recognized sial in the region. The syn-tectonic tholeiite dykes cannot be shown to have fed the greenstone successions and this, together with available geochronology (Barton, 1980) suggests that the sialic crust intruded by the dykes was not a basement to the supracrustal greenstone successions.

The bimodal gneisses and migmatites in the Mankaiana area are, however, considered by Hunter (1974a, 1979) to pre-date the Barberton greenstone belt despite the fact that no direct evidence for this relationship exists and that the oldest age for these rocks (i.e. 3 555 ± 111 m.y., Barton, 1980) suggests that they were, at best coeval with the earliest developed ensimatic crust. The locally developed Dwalile metamorphic suite is considered to have been deposited above basement consisting of the Bimodal Suite even though repeated high strains have largely obscured relationships between the gneisses/migmatites and the supracrustals (Jackson, 1979). Jackson also suggested that the mafic dykes in the Mankaiana area might have fed an overlying greenstone supracrustal assemblage but no direct evidence for this is available.

Because of the striking similarities between the rocks in the Mankaiana area and those of the Badplaas region (including lithological likenesses between the Onverwacht Group and the Dwalile metamorphic suite and the occurrence of banded and bimodal gneisses in both areas), the authors consider that past attempts to genetically segregate the two terranes are largely unfounded. Robb and Anhaeusser (1979) indicate that differences in metamorphic grade and intensity of deformation may relate to different crustal levels for the two areas (cf. Glikson, 1979; Glikson and Lambert, 1976).

The possibility of finding sialic material predating the ensimatic remnants in the bimodal gneiss/migmatite terranes still remains, particularly since the discovery of $\sim$ 3 800 m.y. old basement in the Limpopo Mobile Belt (Barton et al., 1977; Barton, 1980). However, no such material has yet been located in the areas studied here, thereby strengthening the case for primordial simatic crust in the eastern Transvaal and Swaziland.

B. Hornblende Tonalites and Leucocratic Biotite Trondhjemites

Hornblende tonalites and leucocratic biotite trondhjemites occupy large areas of the granitic terrane in both the eastern Transvaal and Swaziland (see distribution of 1b and 1c in Figure 1. These gneisses are homogeneous and are generally characterized by an S > L fabric (i.e. foliation more pronounced than the lineation) which parallels the greenstone/gneiss contact. The tonalites have higher CaO, total Fe, and MgO contents than the more leucocratic trondhjemites and also have correspondingly lower SiO_2 (compare columns 2 and 3, Table 1). The trondhjemite gneisses have, furthermore, a very similar major element chemistry to the leucocratic components of the bimodal gneisses and migmatites previously described.

The tonalite and trondhjemite bodies in the Badplaas region have previously been described as elliptical or rounded, their shapes being outlined by the edges of the Barberton greenstone belt or greenstone septa. The absence of well-defined, elliptical tonalite/trondhjemite gneiss plutons, particularly in the Mankaiana area in Swaziland, has been used by Hunter (1973, 1979) and Hunter et al (1978) to suggest that the Ancient Gneiss Complex should not be correlated with the tonalitic gneisses in the Barberton region. Recent work southeast of Badplaas indicates, however, that the distribution of numerous greenstone enclaves in the granitic terrane largely invalidates the over-simplified impression that only rounded and well-defined plutons exist in the area (Anhaeusser and Robb, 1978). The few elliptical plutons that do occur are confined to the immediate edge of the Barberton greenstone belt, whereas some distance away the shapes of tonalite/trondhjemite bodies are irregular and are not conspicuously outlined by the scattered greenstone xenoliths. Nevertheless it is still possible to recognize discrete tonalite/trondhjemite bodies or "cells" on the basis of their trace element contents (particularly Sr). In the Badplaas region, these "cells" have irregular shapes and may incorporate a number of small greenstone enclaves (Robb, 1980).

In the type area of the Ancient Gneiss Complex the distribution of numerous small, scattered remnants of the Dwalile supracrustals resembles the greenstone enclaves in the Badplaas region. No large, homogeneous tonalite/trondhjemite plutons occur in the Mankaiana region but remapping undertaken by the Swaziland Geological Survey (A.C. Wilson, personal communication, 1979) and Jackson (1979) indicates that a number of small elliptical bodies of hornblende biotite tonalitic gneiss are present. These complement the large body of hornblende tonalite recorded by Hunter (1966) and subsequently included on other maps of the territory (Hunter, 1970, 1973, 1979).

These considerations, together with those of Robb and Anhaeusser (1979), suggest that the tonalite and trondhjemite plutons constitute as much a component of the Ancient Gneiss Complex (including Hunter's (1973) Granodiorite Suite) as they do the equivalent gneiss/migmatite terrane in the Badplaas region. The tonalite and trondhjemite gneisses, together with the migmatites and bimodal gneisses described above, are thus considered to form the dominant portion of the first magmatic cycle.

C. Geochronological and Tectonic Characteristics

The migmatite and gneiss terrane southwest of the Barberton greenstone belt is characterized by Rb-Sr isochron ages ranging from 3 447 ± 168 m.y. to 2 916 ± 33 m.y. with a concomitant range in initial $^{87}Sr/^{86}Sr$ ratios of 0,7000 ± 0,0019 to 0,7018 ± 0,0005 (Barton, 1980). In Swaziland, the migmatitic and gneissic units of the Ancient Gneiss Complex range in age from 3 555 ± 111 m.y. to

3 138 ± 112 m.y. with initial $^{87}Sr/^{86}Sr$ ratios of between 0,6999 ± 0,0016 and 0,7048 ± 0,0022 (Barton, 1980; Davies, 1970; Davies and Allsopp, 1976). In both areas, therefore, the onset of felsic magmatism took place approximately 3 500 m.y. ago within the limits of geochronological error. Furthermore, the development of this early sialic material was largely coeval with the formation of oceanic crust now represented by the extrusive rocks of the Onverwacht Group. This is supported by Barton et al. (1980) who, on the basis of isotopic data, show that the Barberton volcanic rocks (Komati Formation) are coeval with the leucocratic gneisses of the Bimodal Suite and also have indistinguishable initial $^{87}Sr/^{86}Sr$ ratios.

It is evident that the emplacement of units associated with the first magmatic cycle was repeated episodically for ∿ 600 m.y. after the formation of the earliest sial in the area. As Barton (1980) points out, however, the younger ∿ 2 900 m.y. ages may reflect an age of emplacement or a resetting of originally emplaced material that took place sometime after the original formation of the magma and during which period Sr isotopes were re-homogenized. Slightly higher initial $^{87}Sr/^{86}Sr$ ratios in the younger plutons may also reflect the extended residence of these bodies in the crust prior to their subsequent emplacement, possibly as gravitationally induced diapirs. Consequently, the minimum ages attributed to the first magmatic cycle are not necessarily indicative of an overlap with respect to its processes of formation and the inception of the second magmatic cycle.

Tectonic considerations in the Barberton region (Anhaeusser, Robb - in preparation) together with data from the Canadian Archaean (Schwerdtner et al., 1978; Schwerdtner and Lumbers, 1980) indicate that the emplacement of tonalite/trondhjemite gneiss plutons into the greenstone successions was in response to gravitational instabilities that existed because of density contrasts between the two rock types. The formation of primitive sial therefore took place at the same time or shortly before this material was emplaced by diapirism into a higher crustal level than that at which it was generated. This suggests that proto-cratonization was turbulent and that unstable tectonic conditions existed during the first magmatic cycle.

IV. SECOND MAGMATIC CYCLE

A. Multi-component K-rich Batholiths

Whereas the first magmatic cycle is characterized by Na-rich tonalites and trondhjemites, the second cycle invariably involves more potash-rich rocks that are distinctive in terms of their mineralogy, texture, field appearance, age and style of emplacement. Unlike the various units of the first cycle, which were largely emplaced into their present positions by gravity inversion, the different phases of the second magmatic cycle were probably emplaced directly into their present positions by "passive" processes (Pitcher, 1979) involving stoping, cauldron subsidence and assimilation. They are referred to here as *batholiths* because of this distinction and the size and discrete nature of these multi-component bodies (Figure 1).

Outlined in Figure 1 are three large K-rich batholiths, two of which exceed 1 500 km^2 in area. Most detail is available from the Nelspruit batholith occurring to the north of the Barberton greenstone belt (Figure 1, 2a). This extensive massif consists dominantly of a coarse-grained, relatively homogeneous, porphyritic granite or adamellite known locally as the Nelspruit Porphyritic Granite (Robb, 1978) : its average composition is given in Table 1, column 4. It is evident from the chemical composition that these rocks are adamellitic in character. The Nelspruit Porphyritic Granite is characterized by microcline megacrysts, whose development varies from intense, in certain central areas, to moderate in more marginal areas. This very extensive phase is considered to have been emplaced at a relatively high crustal level and to have slowly crystallized by a process of inward nucleation such that a pronounced fractionation trend is evident over the body (McCarthy and Robb, 1978).

An isotopically coeval phase, known as the Hebron Granodiorite, occurs within the Nelspruit batholith both as veins intruding the Nelspruit Porphyritic Granite and as a small, medium-to-fine-grained, homogeneous pluton in the centre of the batholith. This granodioritic phase (Table 1, column 5) is genetically related to the Nelspruit Porphyritic Granite but intruded the latter shortly after its emplacement (Robb, 1978). A similar intrusive granodioritic phase also forms one component of the large potash-rich Mpuluzi batholith, some 30 km to the southwest of the Barberton greenstone belt (Figure 1).

The Mpuluzi batholith, like its Nelspruit counterpart, consists principally of a coarse-grained, homogeneous, porphyritic granite. It has been invaded by linear, commonly dyke-like bodies of homogeneous, medium-grained, pinkish-grey adamellite (Table 1, column 6). This phase has been referred to previously as either the Homogeneous Hood or Lochiel granite (Hunter, 1973. 1974a; Viljoen and Viljoen, 1969a, b). The recent, more detailed, mapping has shown that this granite represents only a single phase within a much larger multi-component batholithic system.

B. Marginal K-rich Migmatites and Gneisses

The batholiths of the second magmatic cycle contain at least three discrete and distinctive cogenetic and broadly coeval phases. In addition, the areas marginal to these batholiths are characterized by K-rich migmatites and gneisses that represent zones of interaction between the homogeneous, passively emplaced magmas of the main massifs and the crust that existed during the final stages in the evolution of the first magmatic cycle. These marginal zones are regarded as a fourth component associated with the batholiths and are best developed in the Crocodile River valley and in areas rimming the Mpuluzi batholith south of the Barberton greenstone belt and in Swaziland (Figure 1, 2b).

The migmatite zones vary considerably in extent, ranging from only a few hundred metres to in excess of 10 km wide. Proceeding from the batholith margins, which seldom display sharp contacts, there is a gradational decrease in porphyritic phases. Nebulites, consisting of migmatites with ghost-like relics of pre-existing rocks, give way to zones in which enclaves are increasingly abundant and where greenstone components ultimately become clearly recognizable. Similar features are recorded in areas flanking granitoid batholiths in the Superior Province of the Canadian Shield (W.M. Schwerdtner, personal communication, 1979; Schwerdtner and Lumbers, 1980).

The migmatites (arterites) of the marginal zones were formed by the injection of "new" magma related to the K-rich batholiths. Numerous anastomosing pegmatite, granite and aplite dykes and veins add to the complexities of the batholith rims and these in turn are responsible for promoting localized zones of metasomatism, palingenesis and granitization. The passive invasion process allowed preservation of pre-existing planar mineral fabrics and minor structures such that the batholith aureoles appear to have inherited, locally, the imprint of the structural (and lithologic) regime of the area prior to the onset of the second magmatic cycle.

Chemically, the rocks in the marginal areas vary considerably and no single analysis could justifiably typify the characteristics of the zone. The average composition derived from nine samples of the Nelspruit migmatites and gneisses listed in Table 1, column 7, should be viewed in this light, although it nevertheless exemplifies the dominant granodioritic nature of the majority of rocks developed in these areas.

C. Geochronological and Tectonic Characteristics

Although the batholiths of the second magmatic cycle are made up of a number of compositionally and texturally discrete phases, geochronological data suggest that these rocks were emplaced into the crust over a shorter period than the sialic units of the first cycle. The various phases of the Nelspruit batholith were apparently formed between 3 211 ± 133 m.y. and 3 149 ± 125 m.y. ago with accompanying peripheral (mainly pegmatitic) phases being dated at 2 927 ± 137 m.y. (Barton, 1980; De Gasparis, 1967). Initial $^{87}Sr/^{86}Sr$ ratios in this suite of rocks range from 0,7007 ± 0,0011 to 0,7052 ± 0,0020. Data available from the Mpuluzi batholith indicate a range in Rb/Sr isochron ages from 3 028 ± 14 m.y. to 2 986 ± 69 m.y. with a range in initial $^{87}Sr/^{86}Sr$ ratios of 0,7013 ± 0,0002 to 0,7054 ± 0,0036 (Barton, 1980; Davies, 1970). The onset of magmatism in the second cycle, therefore, apparently occurred approximately 3 200 m.y. ago and continued for some 300 million years. The initial $^{87}Sr/^{86}Sr$ ratios of most associated phases are low, suggesting that they were derived from primitive material characteristic of the first magmatic cycle. The apparent vast volumes of adamellitic and granitic material constituting the batholiths precludes their derivation from the same mafic precursors considered to be responsible for the earlier tonalites and trondhjemites. It appears likely that the batholiths may therefore be largely shallow-seated bodies forming relatively thin sheets over much of the earlier-formed crust in the region (a concept similar to that of a granitic "hood" or carapace proposed by Hunter (1973) and Viljoen and Viljoen (1969a)).

The various components of the batholiths are post-tectonic and have not undergone the intense deformations that characterize the gneissic and migmatitic rocks of the earlier magmatic cycle. The marginal migmatites and gneisses of these large batholithic bodies contrast markedly with their earlier counterparts, being characterized by potassic leucosomes and more diffuse, schlieric textures (the latter defined by Mehnert, 1968). The marginal zones furthermore display "inherited" structures that were produced during the earlier magmatic cycle, being manifest as nebulites or migmatites with ghost-like relics of pre-existing rocks. These characteristics suggest that the style of batholith emplacement differed from that of the first magmatic cycle when gravity inversions were probably tectonically dominant. The absence of a penetrative fabric in any of the batholith components as well as the ubiquitous marginal migmatite phases that accompany these units is indicative of *passive* emplacement of magma (cf. Pitcher's (1979) "permissive intrusions") at relatively high crustal levels and without subsequent remobilization or re-emplacement. The batholith magmas and their incumbent, more volatile, phases appear to have been passively intruded into the pre-existing crust by processes such as cauldron subsidence, stoping and assimilation.

In view of the large volumes of magma which it generated, the second magmatic cycle is considered to represent the main event contributing to cratonization of the early continental masses and the one during, and subsequent to, which tectonic stability prevailed.

V. THIRD MAGMATIC CYCLE

A. The Late Granite Plutons

Twelve granitic plutons have been identified in the eastern Transvaal and Swaziland, all but one appearing on the map of the area (Figure 1). The plutons are distinguished by their topographic expression, lithology, transgressive mode of emplacement and limited metamorphic effects (Hunter, 1973; Robb, 1978; Viljoen and Viljoen, 1969a, b). Most plutons are homogeneous, coarse-grained, commonly porphyritic, K-rich bodies that, on the basis of their geochemical characteristics, may be regarded as adamellites or granites (*sensu stricto*), although undersaturated syenite bodies occur 15 km southeast of Badplaas (Anhaeusser et al., 1979) and a tonalitic pluton occurs east of Bushbuckridge (Figure 1).

The plutons are classified into two groups embracing an older and a younger category (Hunter, 1973, 1974b; Viljoen and Viljoen, 1969a, b) based partly on field relations established in Swaziland (Hunter, 1973) but principally on the basis of their isochron ages. The emplacement of the older plutons appears to have commenced approximately 2 900 m.y. ago following cessation of the second magmatic cycle. The granite plutons were emplaced into a crustal environment largely thickened and stabilized by cratonization accompanying the two previous cycles.

B. The Older Plutons

Based on Rb-Sr whole rock isochron ages, the older plutons fall within the time space 2 927 ± 59 m.y. to 2 784 ± 53 m.y. (Barton, 1980; Davies, 1970). Physically there is little to distinguish the K-rich granitic bodies from those of the younger plutons, which with the exception of the tonalite body form a rugged terrain characteristic of all remaining plutons in the eastern Transvaal and Swaziland. The older plutons are distinguished geochemically from the younger plutons mainly on the basis of lower K/Na ratios (0,64 - 0,93), higher K/Rb ratios ($\sim$ 260) and lower Rb/Sr ratios (0,15 - 0,28) and are granodioritic in character (Condie and Hunter, 1976; Glikson, 1976; Viljoen and Viljoen, 1969b).

C. The Younger Plutons

Rb-Sr isochron ages suggest that the younger plutons range in age from 2 608 ± 123 m.y. to 2 496 ± 176 m.y. (Barton, 1980; Davies, 1970; De Gasparis, 1967). The bodies are topographically prominent, and the rock types are generally coarse-grained, pinkish coloured, commonly porphyritic adamellites or granites. They differ from the older plutons in possessing higher K/Na ratios ($\sim$ 1,65), lower K/Rb ratios ($\sim$ 166) and higher Rb/Sr ratios (0,66 - 16) (Condie and Hunter, 1976; Viljoen and Viljoen, 1969b). Major element analyses show little chemical distinction between the older and younger plutons (Table 1, columns 8 and 9), the main differences being in the alkali elements.

D. The Na-rich Pluton

The topographically subdued tonalitic pluton to the east of Bushbuckridge (Figure 1) is an anomaly within the late granite (*sensu lato*) plutons. This homogeneous, medium-coarse grained body which is characterized by low K/Na ratios ($\sim$ 0,4), Rb/Sr ratios of between 0,06 and 0,22 and a K/Rb ratio of $\sim$ 180 (Robb, 1977) contrasts with both the older and younger plutons. The tonalite pluton has a Rb/Sr isochron age of 2 784 ± 53 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0,7034 ± 0,0003 making it more akin to the older, granodioritic plutons than to the more evolved younger plutons.

The late granite (*sensu lato*) plutons of the third magmatic cycle generally have higher initial $^{87}Sr/^{86}Sr$ ratios than the components of the first and second magmatic cycles most likely because many, if not all, of these plutons have been derived from the reworking of pre-existing sialic (tonalitic to granitic) crust (Condie and Hunter, 1976).

VI. CONCLUSIONS

1. From a purely descriptive viewpoint it is convenient to categorize the numerous and diverse granite types in the Archaean terrane of the eastern Transvaal and Swaziland, into three broad groups. These three categories also reflect stages in the formation and genetic evolution of the early sialic crust in this area. The concept of three consecutive magmatic cycles, therefore, not only has taxonomic validity but affords an understanding of the processes by which the Kaapvaal craton was constructed.

2. The early stages of *proto-cratonization* in the greater Barberton area were accomplished during the first magmatic cycle. During this event, primitive tonalitic and trondhjemitic

material was derived by melting of an ensimatic source (see Green and Ringwood (1968) and Lambert and Wyllie (1972)), which is envisaged to have covered most of the area under discussion. The emplacement of early sial was largely driven by gravitational overturning (Ramberg, 1967) so that the primitive continental mass was tectonically unstable. Intimate interaction between sial and sima was responsible for the development of complex migmatites, concurrently deformed by the high stresses prevalent in the area at this stage.

3. The dominant processes of *cratonization* were progressively developed during the second magmatic cycle. During this stage, enormous volumes of K-rich magma were passively emplaced into the crust such that by 3 000 m.y. ago it was at least as thick as it is at present ($\sim$ 35 km). These batholiths were probably emplaced at a relatively high crustal level and may occur as sheet-like masses developed over the earlier-formed sialic crust (the granite-greenstone crust produced during the first magmatic cycle).

4. The emplacement of smaller, discrete, post-tectonic plutons associated with the third magmatic cycle coincided with the *termination of cratonization*. These bodies did not contribute significantly either to the construction or stabilization of the early continental crust but nevertheless represent the ultimate cycle in the formation of the granitic basement. Subsequent to this event, the stable platform that had formed was progressively denuded and a succession of cratonic-type volcano-sedimentary basins developed during the Proterozoic era.

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