ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

GEOLOGICAL AND GEOCHEMICAL CHARACTERISTICS OF THE HEERENVEEN AND MPULUZI BATHOLITHS SOUTH OF THE BARBERTON GREENSTONE BELT AND PRELIMINARY THOUGHTS ON THEIR PETROGENESIS

C.R. ANHAEUSSER and L.J. ROBB

INFORMATION CIRCULAR No. 159

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

GEOLOGICAL AND GEOCHEMICAL CHARACTERISTICS OF THE HEERENVEEN AND MPULUZI BATHOLITHS SOUTH OF THE BARBERTON GREENSTONE BELT AND PRELIMINARY THOUGHTS ON THEIR PETROGENESIS

by

C. R. ANHAEUSSER
(Deputy Director, Economic Geology Research Unit)

and

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

ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR No. 159
February, 1982

South African Geodynamics Project Paper No. 69

GEOLOGICAL AND GEOCHEMICAL CHARACTERISTICS OF THE HEERENVEEN AND MPULUZI BATHOLITHS SOUTH OF THE BARBERTON GREENSTONE BELT AND PRELIMINARY THOUGHTS ON THEIR PETROGENESIS

ABSTRACT

The Archaean granitic terrane south and south-west of the Barberton greenstone belt consists predominantly of an older suite of tonalitic and trondhjemitic gneisses into which have been emplaced two large multi-component granitoid bodies known as the Heerenveen and Mpuluzi batholiths. Although geochronologic and Sr-isotopic studies demonstrate that there is little distinction between the ages and initial ratios of the various phases associated with these batholiths, each body displays contrasting textural and geochemical characteristics. The oldest phase is represented by coarse porphyritic granitic rocks into which is intruded a medium-to-fine-grained homogeneous granodioritic phase. Both phases are components of a bimodal association that is, in turn, intruded by a third phase which includes medium-grained pink or grey granodiorite and adamellite dykes feeding a homogeneous sheet-like carapace overlying the coarser porphyritic granites. A fourth phase, consisting predominantly of potassic migmatites and gneisses, occurs in the areas rimming the batholiths and represents the product of interaction between the batholith magmas and components of the pre-existing crust in the region.

Geochemically, the Heerenveen batholith has trondhjemitic affinities whereas the Mpuluzi batholith consists predominantly of potassic granites (granodiorite, adamellite, granite *sensu stricto*). Together with the Nelspruit batholith north of the Barberton greenstone belt the three granitic bodies show a progression in actual values of K_2O, Na_2O, Rb, and Sr with the Nelspruit body having chemical characteristics intermediate between the two.

The batholiths, which represent components of the *second magmatic cycle* (as defined by Anhaeusser and Robb, 1981), are considered to have formed from the partial melting of tonalitic or trondhjemitic source rocks similar to those classified in the first magmatic cycle. Petrogenetic modelling of Rb, Sr, and Ba trace element abundances suggests that the Mpuluzi batholith resulted from the smallest degree of partial melting and that of the Heerenveen body from the highest degree of partial melting. The Nelspruit batholith formed under conditions again intermediate between the two. On cooling the magmas appear to have experienced *in situ* crystal fractionation which, in the Heerenveen batholith, was controlled by plagioclase + quartz with K-feldspar being either "intercumulus" or late stage in character. By contrast, crystal fractionation in the Mpuluzi batholith was controlled by plagioclase + quartz + K-feldspar with the latter mineral being a liquidus phase during most of the solidification history.

Finally it is speculated that all the components of the second magmatic cycle in the Eastern Transvaal and Swaziland are broadly coeval and are a direct response to a period of wide-spread upper mantle/lower crustal de-gassing that may have initiated the melting event approximately 3200 Ma ago.

——— oOo ———

GEOLOGICAL AND GEOCHEMICAL CHARACTERISTICS OF THE HEERENVEEN AND MPULUZI BATHOLITHS SOUTH OF THE BARBERTON GREENSTONE BELT AND PRELIMINARY THOUGHTS ON THEIR PETROGENESIS

CONTENTS

oOo

Published by the Economic Geology Research Unit
University of the Witwatersrand
1 Jan Smuts Avenue
Johannesburg 2000

ISBN 0 85494 726 4

GEOLOGICAL AND GEOCHEMICAL CHARACTERISTICS OF THE HEERENVEEN AND MPULUZI BATHOLITHS SOUTH OF THE BARBERTON GREENSTONE BELT AND PRELIMINARY THOUGHTS ON THEIR PETROGENESIS

I. INTRODUCTION

The granitic terrane south and south-west of the Barberton greenstone belt was examined over the past six years as part of the regional and detailed mapping project associated with South Africa's contribution to the International Geodynamics Programme. Some of the findings relating to the trondhjemitic and tonalitic gneisses and migmatites as well as some of the greenstone xenoliths in the southern part of the Barberton Mountain Land have been described by Anhaeusser (1978, 1980, 1982), Anhaeusser and Robb (1980, 1981a), Mennell *et al.*, (1981), Robb (1981a, b, c, 1982), Robb and Anhaeusser (1982), and Viljoen and Viljoen (1969a, b). In addition, accounts have been given of two late plutons (Dalmein and Boesmanskop) that intrude the trondhjemitic gneisses (Anhaeusser *et al.*, 1982; Robb, 1982) and isotopic studies have been undertaken on many of the granitic rocks in the area (Barton, 1981, 1982; Barton *et al.*, 1982; Oosthuyzen, 1970).

This study documents field observations made in the Badplaas-Lochiel-Amsterdam areas (Fig. 1) where, prior to 1976, no previous geological mapping had ever been undertaken in the Archaean granitic terrane. As a result of the investigations two batholiths (referred to as the Heerenveen and Mpuluzi batholiths) were recognized. These bodies, together with the Nelspruit batholith occupying the area north of the Barberton greenstone belt (Robb *et al.*, 1982), are regarded as being part of a suite of essentially cogenetic granitoid rocks that were emplaced in the Archaean crust of the Eastern Transvaal and Swaziland approximately 3,2-3,0 Ga ago.

In terms of their geochemical, geochronological, and field characteristics the granitic rocks surrounding the Barberton greenstone belt have been classified by Anhaeusser and Robb (1981a) into three magmatic cycles. According to this scheme, the *first magmatic cycle* commenced approximately 3550 Ma ago and involved the formation of Na-rich granitic rocks (tonalites and trondhjemites) and a complex series of bimodal gneisses and migmatites (Robb, 1982; Robb and Anhaeusser, 1982). Driven largely by granitational instability the emplacement of this early sial into an essentially ensimatic regime (like that provided by the magnesian-rich basaltic and peridotitic komatiite sequences found dominating the basal stratigraphic units of the Barberton greenstone belt) resulted in its ultimate fragmentation, with some of the remnants being preserved as greenstone xenoliths.

Superimposed onto this early or proto-cratonization stage of crustal evolution in the Eastern Transvaal, were the granitic events ascribed to the *second magmatic cycle*. During this stage, which Anhaeusser and Robb (1981a) considered to be the dominant cratonization stage, enormous volumes of K-rich magma were passively emplaced into the crust such that by 3000 Ma ago it was at least as thick as at present.

Finally, in terms of Archaean crustal evolution, the events coinciding with the *third magmatic cycle* in the Barberton region involved the emplacement of smaller, discrete, post-tectonic plutons which did not contribute significantly either to the construction or stabilization of the early continental crust. They did, nevertheless, represent the ultimate stage in the formation of the granitic basement coinciding with the termination of cratonization.

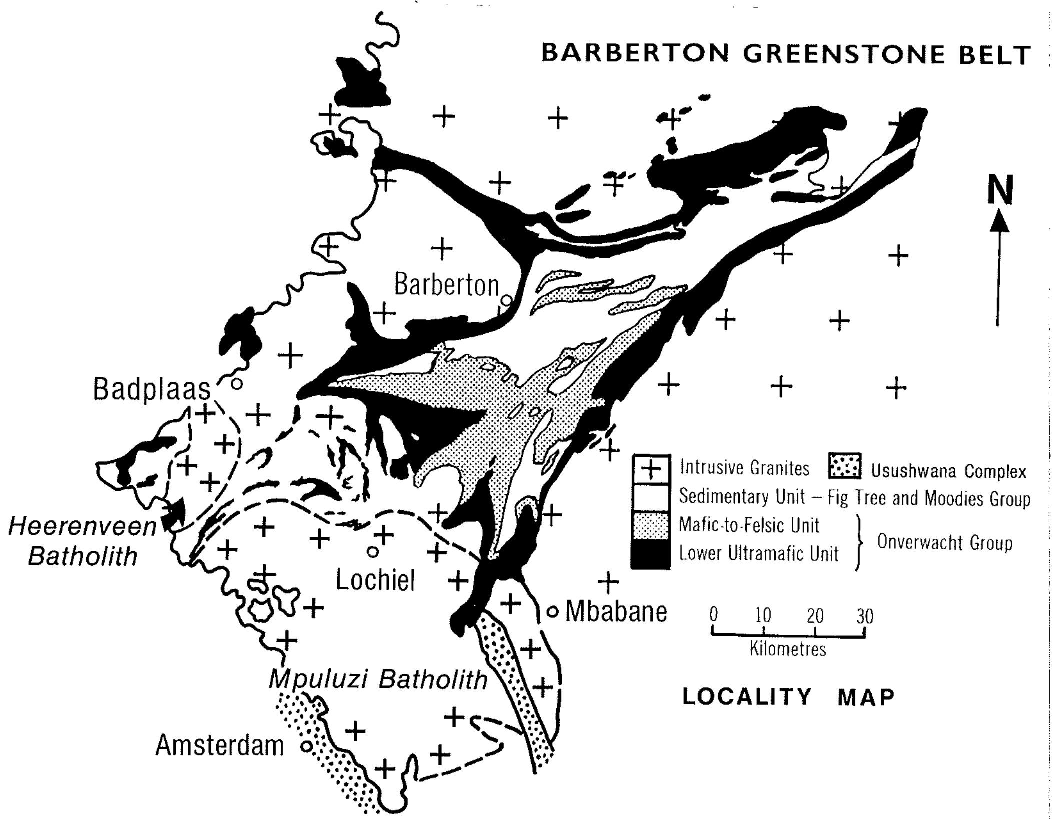
The three magmatic cycles, as outlined above, are portrayed on the 1:250 000 provisional geological map of the Barberton greenstone belt and surrounding granitic terrane in the Eastern Transvaal and Swaziland (Anhaeusser *et al.*, 1981b). The Heerenveen and Mpuluzi batholiths, which are regarded as components of the second magmatic cycle mentioned above, occupy large tracts of the exposed granitic terrane south and south-east of Badplaas (Fig. 1) with the Mpuluzi batholith also extending across the Transvaal border into Swaziland. The regional mapping of the granitic terrane occupied by the batholiths was carried out using aerial photographs at a scale of 1:36 000 but locally some 1:10 000 scale enlargements were employed where more detail was required. This mapping revealed the existence of a number of granite types and textures, the distribution of which are indicated on the 1:250 000 map of the region (Anhaeusser *et al.*, 1981b).

In the sections that follow descriptions are provided of the various granitic phases encountered in the batholiths south of the Barberton greenstone belt. This account complements, furthermore, the study undertaken on the Nelspruit batholith north of the Barberton greenstone belt (Robb *et al.*, 1982) where the petrological, textural, and geochemical characteristics of the granitic rocks are strikingly similar to those of the southern batholiths.

II. REGIONAL GEOLOGY SOUTH OF THE BARBERTON GREENSTONE BELT

South and south-west of the Barberton greenstone belt lies an extensive tract of essentially granitic terrane which is exposed over an area of approximately 5000 km². This region is dissected by numerous streams emanating from the Transvaal Drakensberg Escarpment where Proterozoic cover sequences are developed west of Badplaas (Fig. 1). In the south-west a thin veneer of Phanerozoic Karoo sediments partly covers the granitic terrane forming a flat-to-undulating plateau (approximately 1700-1800 m above sea level) which, in turn, is drained by the Mpuluzi and Great Usutu rivers and their tributaries.

The oldest granitic rocks in the area south of the Barberton greenstone belt are the tonalitic and trondhjemitic gneisses that occur commonly in the form of discrete diapiric plutons and cells intrusive into the greenstones (Anhaeusser and Robb, 1980, 1981a; Robb and Anhaeusser, 1982). Available age determinations show a spread of ages ranging from approximately 3500-2750 Ma for the trondhjemitic gneisses east of Badplaas (Barton, 1981, 1982; Barton *et al.*, 1982; Oosthuyzen, 1970). As most of these gneissic bodies exceed 3200 Ma



<u>Figure 1</u> : *General geological map of the Barberton Mountain Land showing the location of the Heerenveen and Mpuluzi batholiths south and south-east of Badplaas. Further details of these batholiths are portrayed on the 1:250 000 provisional geological map of the Barberton greenstone belt and surrounding granitic terrane in the Eastern Transvaal and Swaziland (Anhaeusser* et al.*, 1981).*

old they have been grouped into the first magmatic cycle (Anhaeusser and Robb, 1981) with the younger ages encountered in some areas being thought of as reflecting ages of emplacement (reset at the time of diapiric intrusion) that may be quite different from crystallization ages (Barton, 1981, 1982).

Numerous greenstone xenoliths rafted off the main body of the Barberton greenstone belt occur as remnants of varying size wedged between the trondhjemitic gneiss plutons. The greenstone xenoliths, only the largest of which are shown in Fig. 1, display a wide range of igneous, volcanic and sedimentary rock types (Anhaeusser, 1980, 1982; Mennell *et al.*, 1981; Viljoen and Viljoen, 1969b, c) and there is now little doubt that these assemblages represent remnants of the lowermost part of the Onverwacht Group (Tjakastad Subgroup) dated at approximately 3500 Ma old (Hamilton *et al.*, 1979).

Intruded into the trondhjemite gneiss-greenstone terrane are the two batholiths mentioned previously. The smaller body referred to as the Heerenveen batholith, is roughly oval in shape, is approximately 28 km long by 17 km wide, and is located south of Badplaas (Fig. 1). The northern third of the batholith is relatively poorly exposed and extends beneath the Transvaal Drakensberg Escarpment. The central portion of the batholith is topographically elevated and has been intruded by a prominent Proterozoic diabase dyke swarm trending mainly in a NW-SE direction (Plate 1). Some dykes have a NE-SW orientation and yet others (mainly post-Karoo in age) trend in a north-south direction. The southern portion of the batholith projects beneath Ecca sandstones making up the Highveld plateau south-east of Carolina.

The larger Mpuluzi batholith appears to be roughly circular in shape but is not fully exposed and extends from Jessievale and Lochiel in the north towards Amsterdam in the south, and from Lothair in the west to Mbabane and Mankayane in Swaziland in the east (see 1:250 000 geological map — Anhaeusser *et al.*, 1981). The northern segment of the batholith forms part of a flat-lying plateau and acts as a watershed between the Komati River in the north and the Mpuluzi and Great Usutu rivers to the south. These drainage systems afford excellent exposure of most of the central and eastern parts of the batholith.

Like the Heerenveen batholith, the Mpuluzi body is also intruded by numerous diabase dykes with a preferred NW-SE strike, parallel to a prominent fracture pattern that is developed across the entire region (Anhaeusser — in prep.). In addition to the dykes, some of which also trend NE-SW and north-south, numerous sills are exposed in the valleys developed in the central and eastern parts of the batholith.

In Swaziland, the eastern part of the Mpuluzi batholith is intruded by a suite of ultramafic, mafic and acid rocks (pyroxenites, gabbros, granophyres, titaniferous magnetite) of the Usushwana Complex (Hunter, 1970; Winter, 1962). The Complex which has an age of approximately 2800 Ma (Davies *et al.*, 1970), has a northern arm located approximately 10 km south-west of Mbabane (Fig. 1) and a larger southern lobe in the Amsterdam area. Both sections of the Complex trend NW-SE parallel to the diabase dyke swarm and the regional fracture system.

The Heerenveen and Mpuluzi batholiths are separated by the Schapenburg greenstone remnant described by Anhaeusser (1982). This remnant forms part of a 'train' of large greenstone xenoliths, each several kilometres in extent, that link up with the Sandspruit and Theespruit formations 30 km ESE of Badplaas (Fig. 1). The largest of these xenoliths is the Weergevonden remnant (Anhaeusser, 1980) which, like the Schapenburg greenstone belt, possesses a wide range of mafic and ultramafic massive and schistose rocks, banded iron-formations and cherts. In addition, the Weergevonden xenolith contains felsic volcanic and pyroclastic rocks whereas at Schapenburg a variety of metasediments (metagreywackes, metapelites and calc-silicate rocks) occurs interlayered with the metavolcanics.

III. THE HEERENVEEN AND MPULUZI BATHOLITHS

A. Introduction

The Heerenveen and Mpuluzi batholiths are each discrete granitic bodies possessing distinctive physical and chemical characteristics. Both are multicomponent bodies consisting of at least three phases : an older coarse-to-very-coarse porphyritic leucogranite and an associated fine-grained leucogranite (both being similar to the bimodal association described in the Nelspruit batholith by Robb *et al.*, 1982), and a younger medium-grained pinkish-grey leucogranite of the type that has been referred to either as the Lochiel or Homogeneous Hood granite (Condie and Hunter, 1976; Hunter, 1973, 1974; Viljoen and Viljoen, 1969a, b) and which, in places, forms what appears to be a carapace that is only locally preserved in high-lying terrain. In addition, areas marginal to the batholiths are characterized by K-rich migmatites and gneisses that represent zones of interaction between the homogeneous, relatively passively emplaced, magmas of the main massifs and the crust that existed during the final stages in the evolution of the first magmatic cycle as defined by Anhaeusser and Robb (1981).

Geochronologic and Sr-isotopic studies carried out on samples from all three phases of the batholiths yielded a Rb-Sr whole rock isochron of 3028 ± 14 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0,7013 ± 0,0002 (Barton *et al.*, 1982). This isochron age is in good agreement with the Rb-Sr whole rock isochron age of 3005 ± 120 Ma obtained by Allsopp *et al.*, (1962) and of 2986 ± 69 Ma published by Davies (1971). It also coincides favourably with the model $^{207}Pb/^{206}Pb$ age of $\sim$ 3075 Ma for zircon separated from these granites by Oosthuyzen (1970). These findings suggest that despite the physical variability of the phases present in the batholiths all the components are isotopically coeval — a feature that is also characteristic of the phases within the Nelspruit batholith (Robb *et al.*, 1982).

Despite their overall similarity the Heerenveen and Mpuluzi batholiths display diverse physical and geochemical properties and, hence, will be described separately in the sections that follow.

B. The Heerenveen Batholith

1. *Field Relationships*

The Heerenveen batholith is topographically prominent over much of its central and southern parts where it attains a maximum elevation of approximately 1800 m. In the north it is less well-exposed and is cut by the Buffelspruit stream (known as the Seekoeispruit in the vicinity of Badplaas) and is approximately 1180 m in elevation in the river valley. Excellent exposure is available in the central and eastern parts of the batholith where the granitic rocks are commonly exposed in extensive domical pavements devoid of soil or vegetation cover (see Plate 1). Also present in the area are numerous intrusive diabase dykes that outcrop prominently and are traceable for many kilometres across the entire region. These dykes coincide with a prominent set of fractures and shear zones which trend predominantly in a NW-SE direction but which are also arranged in a NE-SE direction. Younger dolerite dykes of Karoo age occur less commonly and are generally orientated north-south. Several shear zones in the granites appear to be unrelated to the fracture sets mentioned above and these are generally distinguished by prominent ridges of white vein quartz flanked by extensively sericitized zones.

The Heerenveen batholith appears to be braodly zoned, having a central core consisting mainly of very coarse, porphyritic, high alkali trondhjemites and an outer zone comprised mainly of less porphyritic, medium-grained granodiorites and adamellites which grade progressively into nebulitic and migmatitic zones near the batholith margins.

The central core is dominated by coarse-grained porphyritic rocks in which the megacrysts vary in size, composition, and frequency of occurrence. Certain areas are characterized by intensely porphyritic granite where large, euhedral microcline crystals up to 50 mm in length are developed. The megacrysts generally vary in size in any one outcrop with the large feldspar crystals randomly developed throughout the rock (Plate 2A). In places the granite has a medium-coarse texture and is studded with randomly developed megacrysts, some of which exceed 50 mm in length (Plate 2B). Elsewhere, also in the central zone, quartz megacrysts may occur prominently together with large feldspar crystals and, in places, the granite has an extremely coarse-grained but, nevertheless, even-textured appearance (Plate 2C). In contrast to the porphyritic phases of the Nelspruit batholith described by Robb *et al.*, (1982) the Heerenveen porphyritic granites have generally larger, but more sparsely distributed megacrysts.

Progressing outwards from the central core, the feldspar megacrysts generally become less prominent both in size and number. In places the granitic rocks are only slightly porphyritic or may even be entirely megacryst free.

Also developed in the central zone of the batholith, and intimately associated with the coarse porphyritic phases, is a medium-to-fine-grained, non-porphyritic, homogeneous, even-textured, largely granodioritic phase, which strikingly resembles phases associated with the Hebron and Berlin granodiorite plutons in the Nelspruit batholith. In the Heerenveen batholith the medium-fine-grained granodiorite phase occurs pervasively dispersed throughout the porphyritic granite (and in places the outer zone nebulites and migmatites) as veins and dykelets in a manner identical to that of the bimodal association described in the Nelspruit batholith (Robb, 1977, 1978; Robb *et al.*, 1982). Excellent pavement exposures demonstrating the bimodal association occur on the farms Heerenveen 27IT and Kleintheespruit 28IT in the central and eastern parts of the batholith. As is the case in the Nelspruit batholith, the finer-grained granodioritic phase intrudes the coarse porphyritic phase (Plate 2D) but, as was mentioned previously, all the phases present in the Heerenveen and Mpuluzi batholiths have yielded a Rb-Sr whole rock isochron of 3028 ± 14 Ma suggesting a close genetic relationship.

Outwards from the central, largely porphyritic, core of the Heerenveen batholith, and best demonstrated in a traverse extending from the farm Heerenveen 27IT south-east towards the Schapenburg greenstone belt, there is a progressive change from homogeneous, slightly porphyritic granites into an outer zone where nebulitic phases are encountered. Continuing south-eastwards the nebulites gradually make way for migmatites where, at first, the mafic component is generally light grey but which becomes progressively darker (Plate 2E) until eventually, recognizable mafic greenstone xenoliths are encountered in the trondhjemitic gneisses flanking the Schapenburg greenstone remnant. Also characteristic of the nebulitic and migmatitic marginal zone of the batholith in this area are numerous pegmatite dykes and veins that are commonly intruded parallel to the batholith margins (also parallel to the gneisses and migmatites and the NE-SW striking Schapenburg greenstone belt).

Elsewhere around the rim of the batholith, and where exposure permits, there is evidence of a similar marginal migmatite zone which is gradational into the trondhjemitic gneisses and greenstone xenoliths associated with the first magmatic cycle.

What appears to be a still younger phase of granitic rocks associated with the batholith occurs in the form of pinkish, homogeneous, dyke-like bodies that intrude all other phases so far described, including the nebulitic and migmatitic components. Texturally, as well as by colour, these rocks greatly resemble the pinkish-grey granodiorites and adamellites that constitute the medium-grained "Hood-type" granites and they may represent feeder dykes to the homogeneous carapace found covering parts of both the southern batholiths.

2. *Petrography*

The coarse or very coarse porphyritic granitic rocks of the Heerenveen batholith are mostly light grey to greyish-white in colour and the feldspar megacrysts are also either white or pale pink. The medium-fine-grained granodiorites forming part of the bimodal association are grey or pinkish-grey, as are some of the pegmatite and late homogeneous dyke phases that intrude the eastern and south-eastern part of the batholith.

The dominant components of all the rocks are quartz, plagioclase and microcline. In addition, a wide range of accessory minerals, including biotite, muscovite, chlorite, sphene, magnetite, apatite, and zircon may be encountered in different proportions and varying combinations in the different phases developed in the batholith. The plagioclase (albite-oligoclase) is usually partly or entirely sericitized and in some cases epidote has resulted from saussuritization of the feldspars. The biotite is also altered to chlorite in some areas. Myrmekitic intergrowths are commonly encountered in both the coarse porphyritic as well as the medium-fine-grained phases of the bimodal association but are rare in the homogeneous "Hood-type" granodiorites and adamellites.

The large euhedral feldspar megacrysts consist mainly of microcline and display distinctive cross-hatched twinning or sub-parallel exsolution lamellae. The megacrysts are invariably poikilitic and contain abundant inclusions of quartz, biotite, and especially plagioclase (the latter making up an estimated 40 percent of the megacrysts and being partly sericitized as in the finer-grained matrix). In some areas the megacrysts show good crystal zoning suggesting that the magma was subjected to changing conditions of temperature and pressure during crystallization.

The feldspar megacrysts may have originated in several possible ways. Metasomatism may have played a part but, in view of the extent of the southern batholiths and the absence of any causative process, its effects were probably of a local rather than of a widespread nature. An origin linked with a primary magmatic process or subsolidus growth is favoured as the microcline megacrysts clearly formed late in the paragenetic sequence, thereby encasing smaller grains of earlier-formed quartz, plagioclase and biotite (or muscovite). In this respect the origin of the megacrysts in the Heerenveen body was probably very much akin to that envisaged for the Nelspruit batholith where Robb *et al.*, (1982) considered the porphyritic phases to have formed by *in situ* crystal fractionation with the K-feldspar phenocrysts having nucleated from an "intercumulus" liquid.

3. *Geochemistry*

The various granitic phases developed in the Heerenveen batholith are readily distinguishable in the field on the basis of texture, colour and physical interrelationships. In an attempt to quantify these relationships 40 samples were selected for chemical analysis from the approximately 400 km^2 body (these analyses are listed in microfische tables to be included in the Barberton Geodynamics Volume — in press).

Representative analyses are also included in Table 1 which lists major element as well as Rb, Sr and Ba trace element data from each of the granitic phases recognized in the batholith, but not including analyses from the marginal migmatite zone. The data shows a considerable degree of overlap and the currently available information (lacking as it does REE analyses) does not permit a meaningful differentiation of the various phases to be made. The most significant variations centre around the relative proportions of K_2O and Na_2O as well as the trace element contents. A plot of K_2O versus Na_2O (Fig. 2) shows that the majority of the rocks fall into the tonalite field on the Harpum diagram, but that granodiorites and adamellites are also represented. Closer inspection of the data reveals that the majority of the tonalites (or, preferably, the high alkali trondhjemites) are from the coarse porphyritic phase in the batholith core zone, and that the granodiorites and adamellites are essentially from the medium-to-fine-grained phases, including the dykes of the bimodal association and the "Hood-type" granites.

Fractionation trends within the Heerenveen batholith are illustrated in a series of Harker diagrams (Fig. 3). The plots of SiO_2 v TiO_2, Al_2O_3, Fe_2O_3 as total Fe, MgO and CaO all exhibit a broad inverse relationship, with a fair degree of scatter particularly evident in the SiO_2 v CaO and SiO_2 v Al_2O_3 plots. The plots of SiO_2 v K_2O and Na_2O indicate that the potash and soda concentrations are independent of silica. The fact that a single trend is apparent from the available data suggests that all the phases in the Heerenveen batholith are cogenetic — a feature supported by the geochronological and isotopic data.

C. The Mpuluzi Batholith

1. *Field Relationships*

The Mpuluzi batholith is roughly circular in shape (see 1:250 000 map — Anhaeusser *et al.*, 1981) and is well-exposed over much of its 4000 km^2 areal extent. The northern rim is marked by a steep escarpment with prominent cliffs of granite towering above a lower lying tract made up essentially of trondhjemitic gneisses and migmatites as well as numerous greenstone xenoliths of the first magmatic cycle (Plate 2F). South of this escarpment is a remnant of a once more extensive flat-lying plateau that now acts as a watershed between the drainage systems of the Komati River in the north and the Mpuluzi and Great Usutu rivers in the south. The batholith extends into Swaziland where in the east and south-east there is again an escarpment extending approximately north-south in the vicinity of Mbabane but which swings NE-SW near Mankayane.

East of the Oshoek border post a north-south trending arm of the Barberton greenstone belt extends for approximately 17 km into the batholith, while south of this are the north-west striking dykes associated with the Usushwana Complex. The Mpuluzi batholith shows considerable variation in relief in the east and south-east and the granites are exposed in tors as well as in exfoliated domical pavements devoid of soil and vegetation (Plate 3A).

As with the Heerenveen batholith the Mpuluzi body is cut by numerous, predominantly NW-SE orientated dykes and fractures. Some of the fractures extend across the entire area and beyond and are best seen on satellite images of the Eastern Transvaal and Swaziland. Many of the tributaries of the major rivers in the area follow the fracture zones in the granite and produce V-shaped valleys (Plate 3B).

Unlike the Heerenveen batholith the Mpuluzi massif does not appear to be zoned but has, where exposed, a rim of migmatites and gneisses. These marginal migmatites, like similar zones surrounding the Nelspruit and Heerenveen batholiths, represent zones of interaction between the homogeneous, relatively passively emplaced magmas of the main massifs and the crust that existed during the final stages in the evolution of the first magmatic cycle. The marginal migmatites are heterogeneous in character and range from complex migmatites (Plate 3C) to banded gneisses extensively invaded by pegmatites and other K-rich granitic phases (Plate 3D-3F).

TABLE 1

SELECTED CHEMICAL ANALYSES REPRESENTATIVE OF THE VARIOUS GRANITIC PHASES DEVELOPED IN THE HEERENVEEN BATHOLITH

Phase	A			B			C			D			E	
Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sample	BC11†	BP13†	BC29†	BC1ϕ	BC4†	BC7†	BC2ϕ	BC8†	BP10†	BP4†	ET1†	JV27†	BC19†	BC20ϕ
SiO_2	75,03	73,42	73,39	74,90	72,66	72,24	73,00	75,39	71,70	72,84	72,37	72,82	72,10	74,90
TiO_2	0,17	0,11	0,13	0,15	0,16	0,15	0,25	0,10	0,21	0,23	0,12	0,27	0,15	0,16
Al_2O_3	13,62	14,99	14,97	14,30	14,93	14,53	13,80	14,41	14,71	13,84	13,11	13,51	13,43	13,90
Fe_2O_3*	1,20	1,01	1,20	0,92	1,31	1,12	1,85	0,98	1,82	2,02	1,02	1,76	1,33	1,14
MnO	0,03	0,04	0,02	0,03	0,02	0,02	0,01	0,01	0,02	0,05	0,02	0,07	0,04	0,05
MgO	0,37	0,00	0,00	0,30	0,53	0,00	0,40	0,00	1,65	0,39	0,18	0,63	0,11	0,30
CaO	1,34	1,03	1,49	1,46	1,56	1,30	1,15	0,83	2,02	0,92	0,58	0,98	0,68	0,95
Na_2O	5,72	5,97	6,33	4,20	6,40	6,67	3,40	5,06	5,38	4,82	5,34	3,34	4,43	3,50
K_2O	2,75	3,12	2,32	2,37	2,01	1,72	4,81	4,13	2,15	5,38	4,48	4,93	4,70	4,18
P_2O_5	0,12	0,05	0,05	0,06	0,07	0,05	0,08	0,05	0,11	0,10	0,08	0,03	0,05	0,04
L.O.I.	0,47	0,50	0,69	0,39	0,54	0,83	0,67	0,62	0,38	0,59	0,49	1,14	0,30	0,22
TOTAL	100,82	100,24	100,59	99,08	100,19	98,63	99,42	101,58	100,15	101,18	97,79	99,48	97,32	99,34
Rb	53	118	44	60	69	76	190	207	69	105	317	218	231	170
Sr	655	487	623	640	827	312	190	126	696	633	137	217	117	195
Ba	426	252	322	260	264	150	520	236	285	514	225	940	545	460

Analysts : † Department of Geology, University of the Witwatersrand
ϕ Bergström and Bakker, Johannesburg

* Total Fe as Fe_2O_3

A: Very coarse porphyritic phase

Column 1. Coarse porphyritic, grey, high alkali trondhjemite (Kopje Alleen 726JT)
2. Coarse porphyritic, grey, high alkali trondhjemite (Doornpoort 724JT)
3. Very coarse, quartz-rich porphyritic high alkali trondhjemite (Kleinbuffelspruit 31IT)

B: Coarse porphyritic phase (bimodal association)

Column 4. Coarse porphyritic trondhjemite (Heerenveen 27IT)
5. Very coarse, strongly porphyritic, high alkali trondhjemite (Heerenveen 27IT)
6. Coarse porphyritic trondhjemite (Heerenveen 27IT)

C. Medium-fine-grained phase (bimodal association)

Column 7. Medium-fine-grained, pink, homogeneous granodiorite (Heerenveen 27IT)
8. Medium-fine-grained granodiorite veins in coarse porphyritic phase (BC7) (Heerenveen 27IT)
9. Medium-fine-grained grey trondhjemite (Ida 144IT)

D: Homogeneous "Hood-type" granodiorite/adamellite

Column 10. Medium-fine-grained, grey granodiorite with small, scattered feldspar phenocrysts (Boshoek 442JT)
11. Homogeneous, medium-fine-grained, pink granodiorite (Welgevonden 175IT)
12. Pink, medium-fine-grained adamellite (Klipplaatdrift 179IT)

E: Homogeneous, pink granodiorite/adamellite dykes

Column 13. Fine-grained granodioritic dyke in foliated gneisses (Kleintheespruit 28IT)
14. Homogeneous, pink "Hood-type" granodiorite dyke in foliated gneisses (Kleintheespruit 28IT)

The migmatite zone varies considerably in width, ranging from only a few hundred metres (northern rim) to in excess of 10 km wide (north-west of Mankayane in Swaziland). Proceeding from the batholith margin (which seldom displays sharp contacts), inwards to the batholith centre, there is a gradational change from trondhjemitic gneisses and clearly recognizable greenstone enclaves to nebulites and ghost-like greenstone xenoliths. These, in turn, give way progressively to the homogeneous and porphyritic granite phases of the batholith itself. Similar relationships exist not only with the other batholiths in the Barberton Mountain Land but have also been recorded in areas flanking granitoid batholiths in the Superior Province of the Canadian Shield (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 pegmatitic, granitic and aplitic dykes, like those illustrated in Plate 3C-3F, cause localized metasomatism, palingenesis and granitization of earlier material. Evidence available from the northern marginal zone of the Mpuluzi massif suggests that the emplacement of the batholith took place relatively passively, allowing for the preservation of many of the pre-existing planar mineral fabrics and minor structures. As such the batholith aureole appears to have inherited, locally, the imprint of the structural (and lithologic) regime of the area prior to the onset of the second magmatic cycle (Anhaeusser and Robb, 1981). This relationship can be demonstrated in at least two areas. North-east of the Schapenburg greenstone belt the migmatites and nebulites of the marginal zone are aligned parallel to the contacts of the greenstone remnants. Here the inherited fabric of the marginal migmatite zone is conformable with the older granite-greenstone sequence. Further east, between Lochiel and the Swaziland border, the marginal migmatite zone has inherited a north-east fabric (orientated at right angles to the batholith contact)

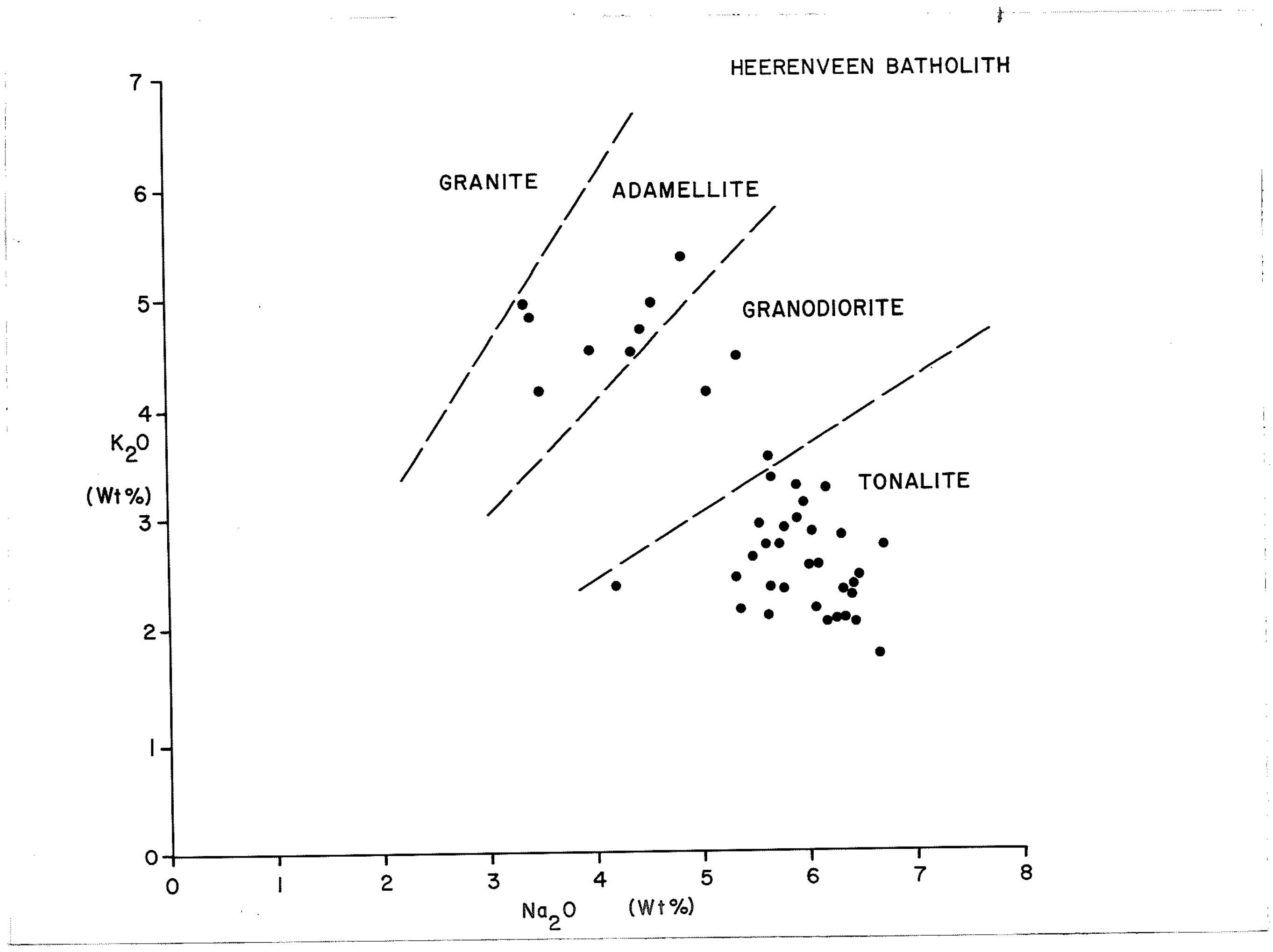


Figure 2 : *K_2O v Na_2O plot of samples collected on the Heerenveen batholith. The majority of the samples fall into the tonalite/trondhjemite field of the Harpum diagram but are notably somewhat enriched in K_2O and are therefore referred to in the text as high alkali trondhjemites.*

which is derived from greenstone successions forming part of the Barberton greenstone belt. These formations, and the trondhjemitic gneisses intruded into them, trend in a NE-SW direction and the migmatized remnants of the greenstones (Plate 3C) project into the batholith aureole before being swamped by the K-rich granitic rocks. Similarly the foliated trondhjemitic gneisses are increasingly engulfed by pegmatitic dykes and veins until they too are entirely replaced (Plate 3D and 3E).

Progressing inwards from the marginal migmatite aureole the Mpuluzi batholith displays features similar to the other multi-component bodies developed in the Barberton Mountain Land. Despite the variations encountered across the body there are essentially three phases that can readily be distinguished in the field. By far the most dominant and wide-spread component is the medium-to-coarse-grained, commonly porphyritic, pink or pinkish-grey adamellite that occupies much of the area between Jessievale and Lochiel in the north and Amsterdam and the Swaziland border in the south and east, respectively. In general, these coarse-grained adamellites are even-textured, homogeneous rocks and the porphyritic phases are characterized by an intense development of medium-to-large (10-40 mm) euhedral microcline megacrysts that occupy 25 per cent or more of the volume of the rocks (Plate 4A). Most of the Mpuluzi adamellites are coarse-grained rocks with moderate phenocryst development but are entirely unlike the coarse-grained, porphyritic, high alkali trondhjemitic phases of the Heerenveen body shown in Plate 2A and 2C.

In places the K-feldspar megacrysts are aligned (Plate 4A) suggesting that their development may have been influenced by tectonic processes. No systematic orientation of the megacrysts could, however, be established regionally and even on the scale of a single outcrop the megacrysts are frequently aligned in differing directions. Rather than representing some regional tectonic control the aligned tabular feldspar megacrysts may be reflecting magma flow, the latter acting randomly as crystallization proceeds.

Generally the adamellites are free of inclusions but isolated nebulitic zones occur in places. These nebulitic patches, like that shown in Plate 4B, are considered to represent either remnants of an early greenstone xenolith or they could reflect metasomatized mafic dyke material emplaced into the Mpuluzi batholith early in its crystallization history.

Associated with the coarse porphyritic granites, but only encountered in a relatively restricted area in the central portion of the Mpuluzi batholith (on the farms Arthurs Seat 220IT and The Gem 231IT), is a medium-fine-grained, even-textured, dark grey granodioritic phase that either occurs alone or in bimodal association with the porphyritic adamellites. The relationship is identical to that found in the Heerenveen body and again resembles the Hebron and Berlin granodiorites described in the Nelspruit porphyritic granite by Robb *et al.*, (1982). Exposure of these rocks in the Mpuluzi batholith is relatively poor but the same dyke-like interfingering of the two components is discernable in places.

The third phase developed in the Mpuluzi batholith is that which in the past has been referred to as the Lochiel or Homogeneous Hood-type granite by Hunter (1973, 1974) and Viljoen and Viljoen (1969a, b). This component is best-developed in the northern and north-eastern parts of the batholith and forms what appears to be a carapace that is only locally preserved in high-lying terrain. In the north, between Jessievale, Lochiel, and Oshoek and across the border in Swaziland, the granite builds a gently rolling plateau standing at elevations between 1200 and 1500 m above sea-level.

The granite is typically a massive, even-textured, grey or pinkish grey, medium- or medium-fine-grained rock and passes gradationally into the coarse-grained more porphyritic variety. Dykes of this phase are also seen

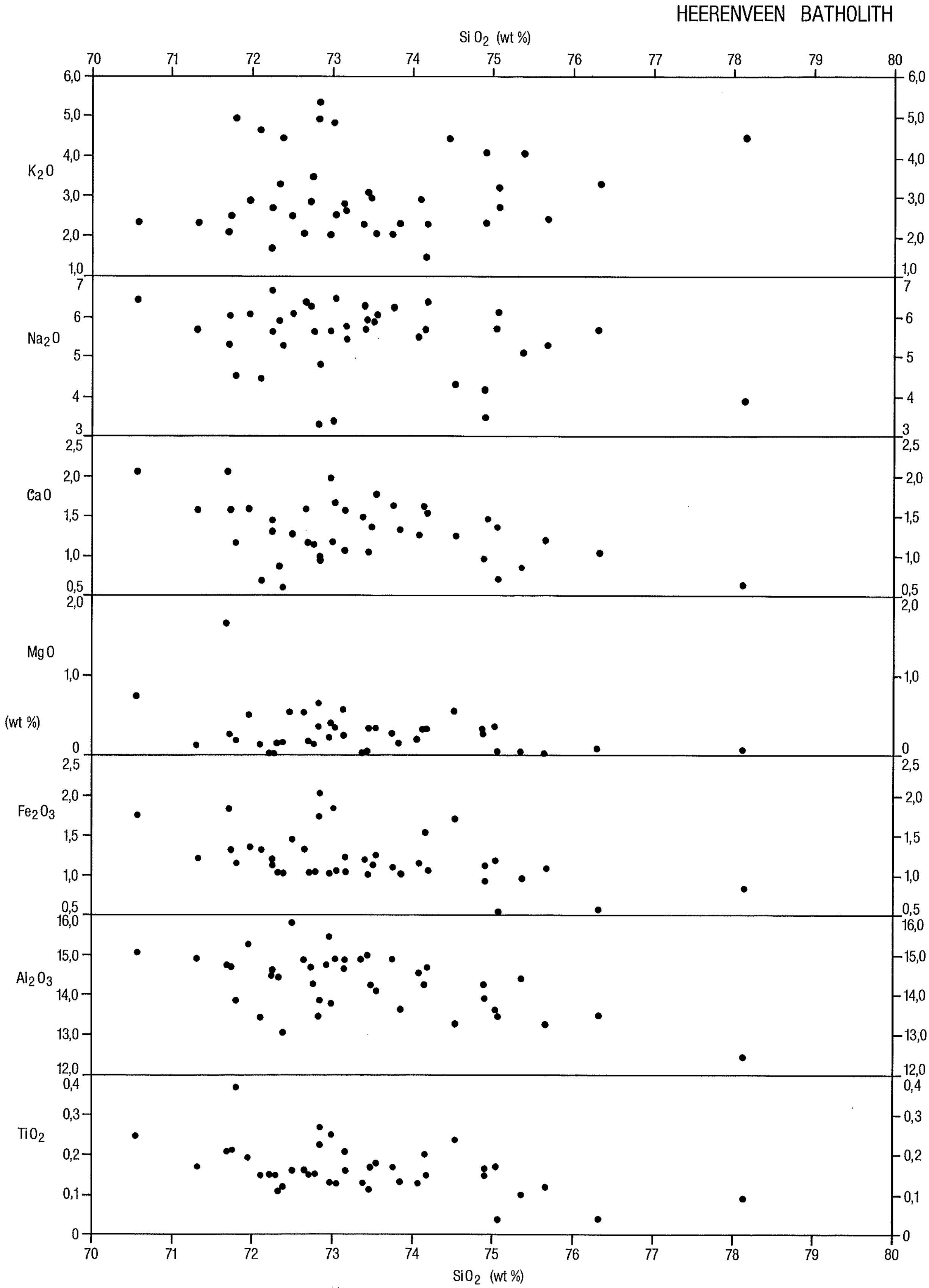


Figure 3 : *Harker variation diagrams for samples representative of all the phases present in the Heerenveen batholith.*

in many areas, particularly in some of the deeply incised valleys in Swaziland, and probably represent feeders to the overlying homogeneous granite carapace. In the area north and west of Mankayane Hunter (1973) noted that the granite passes downwards into the Ancient Gneiss Complex which consists essentially of a series of trondhjemitic and tonalitic gneisses and associated migmatites grouped by Anhaeusser and Robb (1981) into their first magmatic cycle. In this contact zone complex migmatites are found, the latter being cut by narrow dykes and thin sheets of grey granite as well as pegmatites. Hunter (1973) showed that the numbers of these dykes and sheets increased upwards so that only fragments of gneiss remain. Higher still he noted that the zone is essentially granite with wisps and xenoliths of gneiss, which are usually deformed. Metasomatism was also observed in the gneisses and Hunter described porphyroblasts of plagioclase and, near the granite, microcline making an appearance in the gneisses. With a gradual increase in the abundance of these porphyroblasts the gneiss texture is destroyed and there is a gradation into the grey granite. All these features, noted by Hunter (1973), are typically like those found in the marginal migmatite aureoles of the batholiths.

2. *Petrography*

The coarse-grained, homogeneous, porphyritic adamellites forming the dominant phase of the Mpuluzi batholith consist mainly of quartz, microcline, plagioclase (albite-oligoclase), and subordinate biotite. Accessory components include magnetite, sphene, zircon, myrmekite, apatite, muscovite and chlorite. The feldspar megacrysts are mainly microcline and developed late in the paragenesis as is indicated by the presence of numerous quartz and plagioclase feldspar inclusions in the euhedral to subhedral poikilitic crystals. The plagioclase is invariably partially or totally sericitized and some of the biotite is partly altered to chlorite.

The medium-grained, homogeneous, dark grey granodiorites that constitute part of the bimodal association contain abundant khaki-green or brownish biotite together with quartz, plagioclase (albite-oligoclase) and subordinate microcline, myrmekite, sphene, apatite, magnetite, muscovite, chlorite and sericite.

The homogeneous "Hood-type" granodiorites or adamellites are in places either pink, grey, or pinkish-grey. No obvious distinction can be detected in the mineralogy of these differently coloured granites and both varieties contain abundant quartz, microcline, and plagioclase (albite-oligoclase), together with lesser amounts of biotite, muscovite, apatite, sphene, zircon, chlorite, and magnetite. The plagioclase feldspars are often altered to sericite or epidote and biotite is altered to chlorite. Hunter (1973) also reported the presence of some hornblende as well as allanite from Swaziland specimens examined.

Pegmatites located in a 5 km-wide belt extending south-eastwards from the Transvaal/Swaziland border to Mbabane carry economic minerals of which cassiterite is the most important. Other rare minerals found in the pegmatites in this belt include yttrotantalite, beryl, monazite, columbite and euxenite (Hunter, 1973). The cassiterite has not been mined from the pegmatites but some has been recovered from alluvial and elluvial workings (Davies, 1964).

The marginal migmatite zones are characterized by a heterogeneous assemblage of rock types containing the full range of minerals already described for the other granitic phases developed in the Mpuluzi batholith. In some areas metasomatism of greenstones is evident and K-feldspar porphyroblasts occur in some gneisses, the melanocratic varieties of which sometimes contain hornblende as the dominant ferromagnesian mineral (Plate 3F).

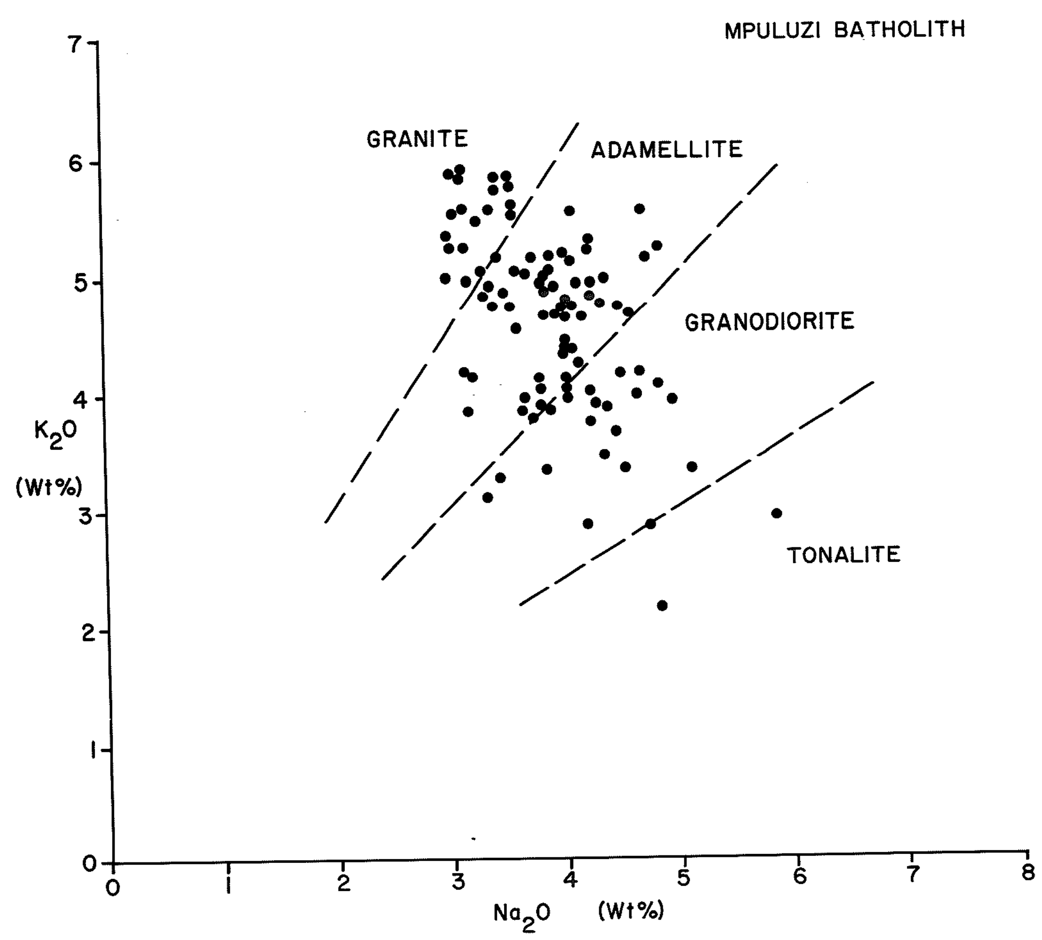


Figure 4 : *K_2O v Na_2O plot of samples collected on the Mpuluzi batholith. The majority of the samples fall into the adamellite field of the Harpum diagram but there is a notable range of compositions from granodiorite to granite (sensu stricto).*

TABLE 2

SELECTED CHEMICAL ANALYSES REPRESENTATIVE OF THE VARIOUS GRANITIC PHASES DEVELOPED IN THE MPULUZI BATHOLITH

Phase	A			B	C		D				E					F				
Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sample	JV36	GM7	LR4A	JG7A	JG5	JG7B	LR2	LR48	MF13	L03	L05	MF8	OK7	BB10	H506	L04A	L04B	MF2A	OK12	JG1A
SiO_2	74,15	73,78	73,00	72,95	63,15	69,64	74,00	70,68	75,47	71,11	70,54	73,75	75,92	73,99	74,95	64,38	66,87	56,13	63,69	64,30
TiO_2	0,24	0,14	0,23	0,17	1,43	0,45	0,25	0,50	0,14	0,25	0,65	0,20	0,07	0,23	0,09	1,33	0,66	1,24	0,48	0,50
Al_2O_3	13,55	14,27	13,78	13,03	15,30	13,90	14,14	14,67	13,53	14,78	14,41	13,75	13,82	14,01	13,87	14,73	14,62	17,42	16,93	16,50
Fe_2O_3*	1,32	1,29	1,67	1,65	5,75	2,92	2,10	3,05	1,36	1,60	2,89	1,56	1,00	1,96	1,07	5,93	4,79	7,81	4,06	3,65
MnO	0,01	0,01	0,03	0,02	0,12	0,03	0,02	0,05	0,03	0,05	0,08	0,02	0,02	0,03	0,04	0,11	0,10	0,11	0,06	0,06
MgO	0,27	0,26	0,43	0,75	2,17	0,62	0,21	0,55	0,17	0,43	1,08	0,07	0,09	0,16	0,25	2,40	1,77	2,53	1,03	1,64
CaO	1,11	0,46	1,03	0,92	3,78	1,23	1,03	1,54	0,82	1,30	2,06	1,78	0,55	0,93	1,05	3,86	2,63	4,71	3,42	3,76
Na_2O	3,69	3,00	3,28	3,60	4,20	4,64	3,41	4,68	4,11	3,50	3,68	4,50	3,51	3,58	4,04	3,32	3,14	4,82	4,51	4,76
K_2O	5,01	5,36	5,49	5,02	2,86	3,98	5,81	4,17	4,26	4,85	3,96	4,17	5,81	5,52	4,79	3,10	5,24	4,06	1,31	2,83
P_2O_5	0,05	0,06	0,07	0,07	0,57	0,19	0,06	0,20	0,05	0,07	0,11	0,06	0,04	0,06	0,02	0,58	0,33	0,79	0,15	0,36
L.O.I.	0,69	0,60	0,53	0,63	0,62	1,31	0,92	0,60	0,62	1,08	0,65	0,50	0,57	1,56	0,53	0,60	0,38	0,52	0,93	0,65
TOTAL	100,09	99,23	99,54	98,81	99,95	98,91	101,95	100,69	100,56	99,02	100,11	100,36	101,40	102,03	100,70	100,34	100,53	100,14	96,57	99,01
Rb	230	184	205	272	240	225	142	184	214	189	137	227	292	188	-	93	204	87	131	122
Sr	195	66	244	224	737	743	166	342	146	791	325	177	61	319	-	999	1254	1870	589	769
Ba	995	349	185	656	1008	967	1103	432	373	2024	880	482	233	886	-	1048	1268	2762	228	1200

Analyst : Department of Geology, University of the Witwatersrand

* Total Fe as Fe_2O_3

A: Coarse, homogeneous, pink, porphyritic adamellites

Column 1. Coarse, homogeneous adamellite (Pittville 197 IT)
2. Very coarse, reddish-pink, porphyritic adamellite (Fernie 243 IT)
3. Very coarse, porphyritic, pinkish-grey adamellite associated with sample LR4B (Damesfontein 226 IT)

B: Coarse, homogeneous, pink, porphyritic adamellite phase (bimodal association)

Column 4. Coarse porphyritic phase associated with sample JG7B (Arthurs Seat 220IT)

C: Medium-grained, homogeneous, dark grey granodioritic phase (bimodal association)

Column 5. Medium-grained biotite-rich dark grey granodiorite (Arthurs Seat 220IT)
6. Dark grey, medium-fine-grained granodiorite phase associated with sample JG7A (Arthurs Seat 220IT)

D: Pink/grey medium-fine-grained "Hood-type" granodiorites/adamellites

Column 7. Medium-fine-grained pink, homogeneous adamellite (Umpilusi 98IT)
8. Dark pinkish-grey, fine-grained granodiorite phase associated with LR4A (Damesfontein 226IT)
9. Medium-fine-grained pinkish homogeneous granodiorite (Amsterdam 183IT)
10. Medium-grained, pale pinkish-grey adamellite, nebulitic in part (The Brook 196IT)

E: Grey, homogeneous "Hood-type" granodiorites/adamellites

Column 11. Grey, weakly foliated, granodiorite (Welgevonden 175IT)
12. Medium-coarse, homogeneous, grey granodiorite (Amsterdam 183IT)
13. Medium-fine-grained, grey, granodiorite near tin prospects (Bettysgoed 213IT)
14. Medium-fine-grained granodiorite exposed in quarry (Aankomst 191IT)
15. Homogeneous granodiorite/adamellite, Swaziland (Hunter, 1971)

F: Marginal migmatite zone granitic gneisses

Column 16. Grey, foliated, gneiss (migmatitic in part) (Welgevonden 175IT)
17. Very coarse, pinkish, foliated adamellite associated with gneisses and migmatites at same locality as L04A (Welgevonden 175IT)
18. Foliated, dark grey, porphyritic gneiss with pink phenocrysts (megacrysts) (Elandspruit 184IT)
19. Banded gneiss near tin prospect and Swaziland border (Oshoek 212IT)
20. Porphyritic dark grey gneiss cut by pegmatites and homogeneous medium-fine-grained granodioritic phase (Caledonia 97IT)

3. *Geochemistry*

As with the Heerenveen batholith the various phases present in the Mpuluzi body are readily identifiable mesoscopically on the basis of texture and colour and physical relationships. Geochemical analyses carried out on 103 samples from the multi-component body show a considerable degree of overlap (data listed on microfische in Barberton Geodynamics Volume — in press). Selected analyses representative of the various phases encountered in the batholith are presented in Table 2. Examination of this data shows that there is little to distinguish between the coarse porphyritic phase and the homogeneous "Hood-type" granodiorites and adamellites. The medium-fine-grained, dark grey granodiorites of the bimodal association are, however, chemically distinctive and show lower concentrations of SiO_2, and K_2O and greater amounts of TiO_2, Fe_2O_3 as total Fe, MgO, CaO and Na_2O. They are also enriched in Sr relative to most other phases not associated with migmatized greenstones.

The marginal migmatite zone is difficult to quantify geochemically because of sample heterogeneity. In Table 2, five samples from this zone are listed to demonstrate the nature of some of the components encountered in this environment. The rocks listed range from tonalites to granodiorites and adamellites. Excluded are trondhjemites and a wide range of hybrid products resulting from the granitization of greenstones, as well as some of the pegmatitic and aplitic phases that commonly occur as an intricate stockwork in the batholith aureole.

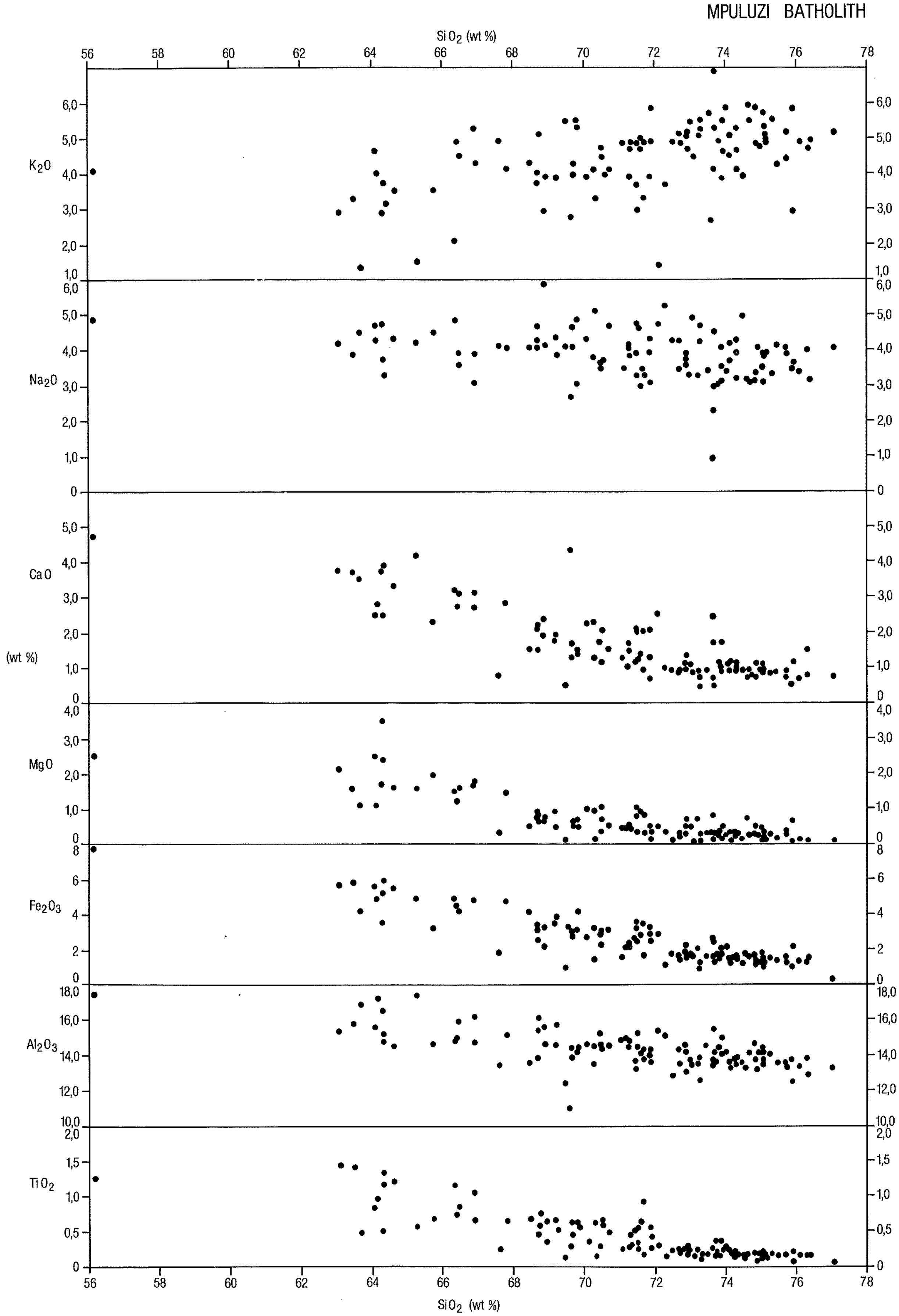


Figure 5 : *Harker variation diagrams for samples representative of all the phases present in the Mpuluzi batholith.*

Probably the most significant variation that may be discerned from the geochemical data again centres around the relative proportions of K_2O and Na_2O in the rocks. In Fig. 4 a plot of these elements shows that the majority of samples fall within the range granodiorite through adamellite to granite (*sensu stricto*), with adamellites being the dominant rock type. This is in marked contrast to the Heerenveen batholith where most of the rocks are high-alkali tonalites or trondhjemites (Fig. 2). The petrogenetic significance of this variation will be discussed in a later section.

Variations in the composition of the Mpuluzi batholith are best illustrated in a series of Harker diagrams (Fig. 5). Despite the fair degree of scatter, the plots of SiO_2 v TiO_2, Al_2O_3, Fe_2O_3 as total Fe, MgO and CaO all show an inverse relationship and the curves of liquid descent are an indication that differentiation of the magma is essentially a process of crystal fractionation. While the ferromagnesian components are strongly fractionated others such as K_2O and Na_2O are less affected and show little or no interdependence on the availability of SiO_2. Once again, like the Heerenveen body, the combined geochemical and geochronological data is supportive of the Mpuluzi body being made up of a cogenetic sequence of magmatic events.

IV. TOWARDS A PETROGENETIC MODEL FOR THE HEERENVEEN AND MPULUZI BATHOLITHS

A. Bulk Compositional Variations

Differences in the mesonormative compositions of the Mpuluzi and Heerenveen batholiths are portrayed in Qtz-Ab-Or and An-Ab-Or ternary diagrams in Fig. 6. It is evident that despite the overlap existing between the two fields the overall characteristics of the two batholiths are significantly different. This is also clearly apparent in the compilation of K_2O/Na_2O and Rb/Sr averages listed in Table 3. The majority of samples from the Heerenveen batholith plot outside the envelope which encompasses a variety of projected thermal minima and eutectic points in the Qtz-Ab-Or diagram and, in fact, straddle the plagioclase-quartz tie-line for P_{H_2O} = 5kb. By contrast, the majority of samples for the Mpuluzi batholith fall within or near this envelope. Similarly, in the An-Ab-Or diagram most samples from the Heerenveen batholith fall within the plagioclase solid-solution field and only a small proportion extend along the projected feldspar cotectic. With the Mpuluzi batholith, however, a significant number of samples plot along the cotectic, with the remainder falling in the plagioclase solid-solution field. In short, if it is assumed that the two sample populations are adequately representative, then it is apparent that crystallization was controlled by a different liquid-line-of-descent in each of the two batholiths.

The trend which emerges for the Heerenveen population reflects a solidification history whereby the majority of rocks crystallized with two phases on the liquidus (namely quartz + plagioclase solid solution). Only during the final crystallization increments were three phases (i.e. quartz + plagioclase + K-feldspar) in equilibrium. By contrast, the Mpuluzi batholith is more "differentiated" overall and a far smaller increment of crystallization occurred with only two phases on the liquidus. Instead, the bulk of the solidification occurred with quartz + plagioclase + K-feldspar in equilibrium. These considerations explain, in part, the observed bulk compositional differences between the two batholiths and are viewed quantitatively in a later section.

B. Trace Element Variations

The Mpuluzi and Heerenveen batholiths are characterized by distinctive trace element signatures which are manifest mainly as differences in the Rb contents of the two bodies (Fig. 7). These differences can be quantitatively modelled in terms of the crystallization sequences described above. However, it is necessary first to consider whether the parental magmas of the Mpuluzi and Heerenveen batholiths were in any way different.

1. *Parental Magma Composition*

Compositional differences between the Heerenveen and Mpuluzi batholiths have been demonstrated in the K_2O v Na_2O plots in Figs. 2 and 4. Here it was shown that the samples from the Heerenveen batholith plot mainly in the tonalite field. By contrast, the bulk of the Mpuluzi batholith is adamellitic to granitic *(sensu stricto)* in composition. This observation is of particular interest in view of the suggestions made by Robb *et al.*, (1982) concerning the Nelspruit batholith where it is envisaged that the parental magma was derived from an older, predominantly tonalitic crust. In view of the broad similarities which exist between the Mpuluzi and Heerenveen batholiths, on the one hand, and the Nelspruit batholith on the other, it is not unreasonable to suggest that a similar source applied to the generation of the parental magma of all three batholiths. If this is the case, and because the composition of an anatectic derived from a tonalitic or trondhjemitic source approaches that of its parent only after a significant proportion of melting has occurred (Brown, 1970), it is logical to suggest that the Heerenveen parent magma was derived by a significantly greater degree of partial melting than the Mpuluzi parent magma.

This can be tested quantitatively in terms of the distribution of trace elements between melt and envisaged source rock. In Part 1 of the Appendix the trace element abundances of various melt fractions derived from a typical tonalite source are calculated. The Mpuluzi parental magma is considered to have been derived by an arbitrary 20% partial melting, yielding a Rb content of 170 ppm and 664 ppm Sr. By contrast, the Heerenveen parental magma is considered to have been derived by 70% partial melting of the same source rock, a process which results in a lower Rb content of 81 ppm and higher Sr content of 833 ppm. These sets of figures agree fairly well with the *relative* abundances indicated in the averaged Rb and Sr data presented in Table 3. The higher Sr contents envisaged in the theoretical parental magmas are a function of the Sr content assumed for the tonalitic parent, the latter being somewhat higher than the typical values indicated for the Theespruit and Kaap Valley plutons (see for example Table 3). The reason for the selection of the higher Sr content in the envisaged tonalitic source rock will become apparent later.

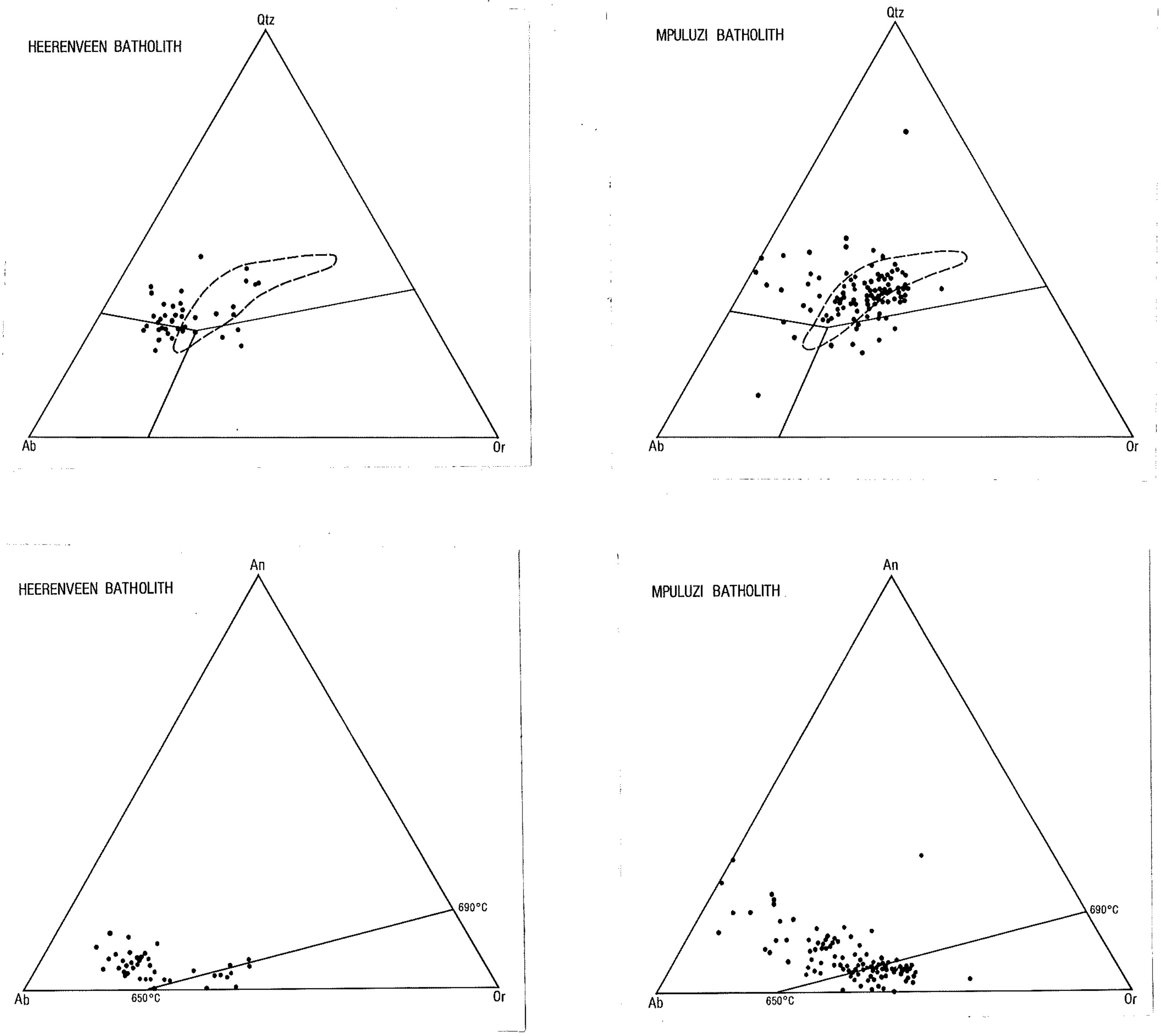


Figure 6 : *Ternary plots of mesonormative Qtz-Ab-Or and An-Ab-Or for samples from the Mpuluzi and Heerenveen batholiths. Projected phase boundaries are for P_{H_2O} = 5 kb from Luth et al., (1964) and Kleeman (1965). The dashed field in the Qtz-Ab-Or plots represents a broad envelope of projected eutectic points and thermal minima for a variety of P_{H_2O} and Ab/An ratios from Luth et al., (1964) and von Platen (1965).*

TABLE 3

AVERAGED GEOCHEMICAL DATA DEMONSTRATING THE PROGRESSIVE VARIATION IN K_2O, Na_2O, Rb AND Sr VALUES FOR VARIOUS GRANITIC BODIES IN THE BARBERTON MOUNTAIN LAND

	No. of Samples	K_2O	Na_2O	K_2O/Na_2O (range)
Mpuluzi batholith	103	4,55	3,88	1,23 (0,50-3,09)
Nelspruit batholith	99	4,09	4,25	0,99 (0,15-2,37)
Heerenveen batholith	40	3,06	5,54	0,70 (0,26-2,39)
Theespruit trondhjemite pluton	43	1,94	5,61	0,35 (0,22-0,90)
Kaap Valley tonalite pluton	51	1,38	5,40	0,26 (0,10-0,45)
——— o0o ———				
	No. of Samples	Rb	Sr	Rb/Sr (range)
Mpuluzi batholith	103	186	338	1,17 (0,05-4,79)
Nelspruit batholith	99	114	463	0,36 (0,03-5,37)
Heerenveen batholith	40	107	515	0,40 (0,05-2,31)
Theespruit trondhjemite pluton	43	48	565	0,09 (0,04-0,31)
Kaap Valley tonalite pluton	51	56	574	0,09 (0,04-0,38)

In summary, both relative and absolute trace element abundances in the Heerenveen and Mpuluzi batholiths are consistent with their having been derived by different degrees of partial melting of a similar tonalitic source rock. As suggested for the Nelspruit batholith this model probably reflects a derivation of these southern batholiths by widespread partial melting of the pre-existing tonalite and trondhjemite gneiss/migmatite crust (Robb *et al.*, 1982).

2. *In Situ Crystal Fractionation*

The trace element characteristics of the Heerenveen and Mpuluzi batholiths are portrayed in Rb v Sr and Rb v Ba plots in Fig. 7. It is evident that the Heerenveen body is characterized by a lower Rb content than the Mpuluzi body and also by a more limited spread in Sr and Ba than in the latter. The bulk of the samples from both bodies define a crude negative correlation in the case of Rb v Sr and Rb v Ba.

These trace element trends can be quantitatively modelled in terms of *in situ* crystal fractionation. These considerations need to take into account the crystallization sequence discussed earlier, as well as the envisaged parental magma compositions. In the case of the Heerenveen batholith the model envisages an initial 75% increment of crystallization occurring with 63% plagioclase, 30% quartz and 7% biotite on the liquidus (see Part 2 of the Appendix). The final 25% increment of crystallization sees the incoming of K-feldspar on the liquidus such that the crystal extract was modified to 48% plagioclase, 25% quartz, 34% K-feldspar and 4% biotite. The distribution of Rb, Sr and Ba during this crystallization sequence is calculated in the Appendix and is also plotted in Fig. 8. If it is assumed that "real" rocks comprise a "cumulate" component together with a variable amount of "intercumulus" or liquid component (McCarthy and Hasty, 1976; McCarthy and Robb, 1978) then the field encompassed by the solid or "cumulate" trend and the liquid-line-of-descent in Fig. 8 is not dissimilar to that of the empirical data for the Heerenveen batholith in Fig. 7.

With respect to the Mpuluzi batholith, the model envisages a much larger increment of crystallization in which K-feldspar is on the liquidus. Consequently, an initial 15% of crystallization is considered to have occurred with 55% plagioclase, 40% quartz, and 5% biotite on the liquidus with the subsequent 85% increment comprising a crystal extract of 46% plagioclase, 25% quartz, 25% K-feldspar and 4% biotite (see Part 2 of the Appendix). The distribution of Rb, Sr and Ba during this crystallization sequence is also calculated in the Appendix and plotted in Fig. 9. It is evident that the model trends clearly accommodate the higher Rb characteristics of the Mpuluzi batholith (i.e. this being a function of the higher Rb content in the parental magma envisaged for the Mpuluzi suite) and also the greater variation in Sr and Ba contents than in the Heerenveen batholith. Again, the field encompassed by the model solid and liquid trend lines in Fig. 9 is not dissimilar to that of the empirical data for the Mpuluzi batholith in Fig. 7.

In summary, the major and trace element data for the Heerenveen and Mpuluzi batholiths place constraints on suggestions concerning the origin of the parental magma to these suites and also the nature of *in situ* crystallization within these bodies. The Mpuluzi magma is considered to have been derived by a small (≅ 20%) degree of melting of a tonalite-trondhjemite precursor, whereas the Heerenveen magma appears to have been derived by a significantly larger (≅ 70%) degree of melting of a similar precursor. Crystal fractionation within these two bodies was probably dominated by plagioclase + quartz in the case of the Heerenveen batholith with the K-feldspar component being either "intercumulus" or late-stage in character. On the other hand, crystal fractionation in the Mpuluzi batholith appears to have been largely controlled by plagioclase + quartz + K-feldspar with the latter mineral being a liquidus phase during a major proportion of the solidification history. It is pertinent to point out that a very similar petrogenetic scheme is envisaged for the Nelspruit batholith (Robb *et al.*, 1982) but that the characteristics of this suite are, in many respects, intermediate between those of the Heerenveen and Mpuluzi batholiths.

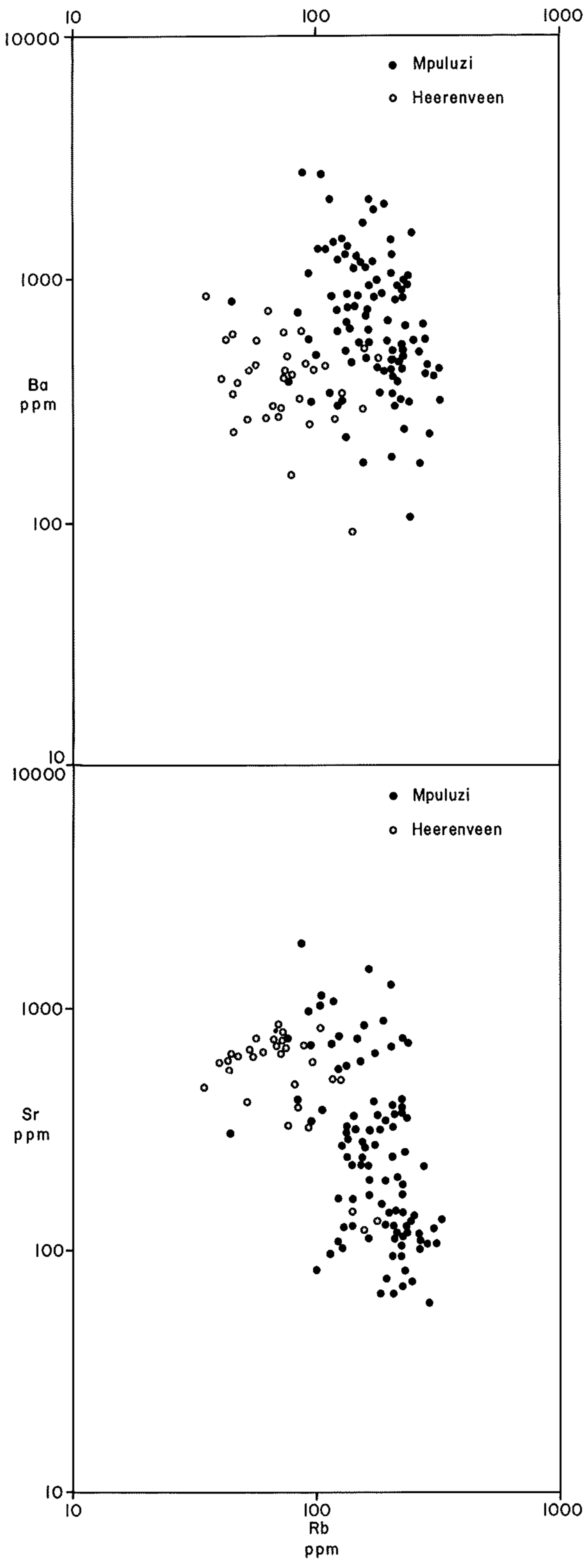


Figure 7 : *Plots of Rb v Sr and Rb v Ba for samples from the Mpuluzi (enclosed dots) and Heerenveen (encircled stars) batholiths.*

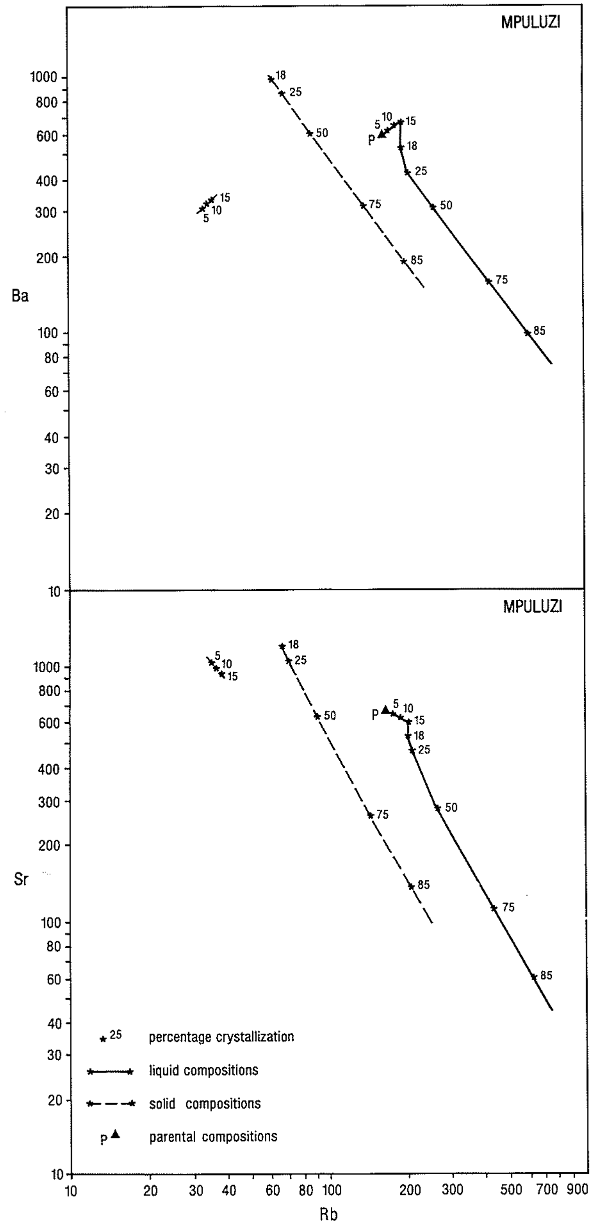


Figure 9 : *Model trends showing the effects of in situ fractional crystallization in the Mpuluzi batholith, in terms of Rb v Sr and Rb v Ba plots. Explanation of the diagram is similar to that in Fig. 8. In this case, however, an initial 15% increment of crystallization is characterised by a liquidus assemblage comprising 55% plagioclase : 40% quartz : 5% biotite with the subsequent 85% increment having 46% plagioclase : 25% quartz : 25% K-feldspar : 4% biotite on the liquidus. Parental composition (P) is calculated in Part 1 of the Appendix while model parameters are provided in Part 2.*

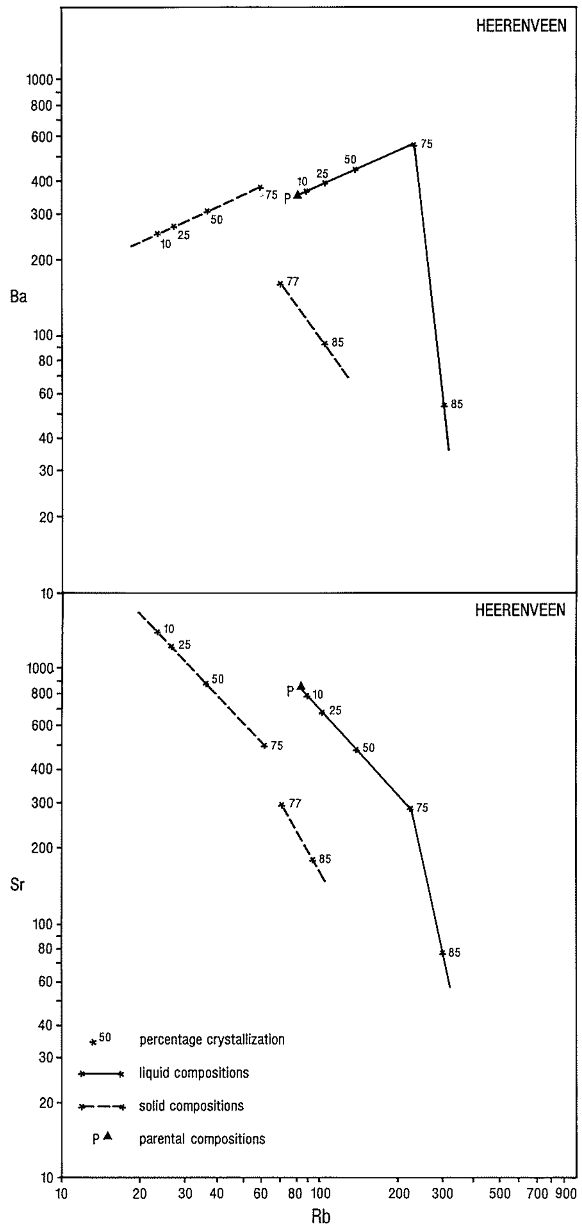


Figure 8 : *Model trend showing the effects of in situ fractional crystallization in the Heerenveen batholith, in terms of Rb v Sr and Rb v Ba plots. Parental magma composition (calculated in Part 1 of the Appendix) is at P; from this melt a crystal extract comprising 63% plagioclase : 30% quartz : 7% biotite is removed for a 75% crystallization increment. The evolving composition of the rest magma is shown by a solid line from P, while the composition of the solid phase (i.e. crystal extract) is shown by the dashed line. After 75% crystallization, the model assumes the incoming of K-feldspar on the liquidus so that the crystal extract changes to an assemblage comprising 48% plagioclase : 25% quartz : 23% K-feldspar : 4% biotite. This causes a marked inflection in the distribution of Rb, Sr and Ba as a result of the changes in the bulk partition coefficient. Details of the model parameters can be found in Part 2 of the Appendix. Note that the composition of "real" rocks, which are likely to contain a variable component of "intercumulus" liquid in addition to the "cumulate" (solid) component, will probably lie in a field encompassed by both liquid and solid trend lines in these plots.*

V. CONCLUSIONS

1. The Heerenveen and Mpuluzi batholiths south of the Barberton greenstone belt together with the Nelspruit batholith in the north (as well as the Pigg's Peak batholith in northern Swaziland — see 1:250 000 geological map by Anhaeusser *et al.*, 1981), are classified into the *second* of three magmatic cycles devised by Anhaeusser and Robb (1981) to represent a schematic breakdown of the granitic rocks in the Eastern Transvaal and Swaziland. The components of the second magmatic cycle are noteworthy in that they occupy large surface areas relative to the other granitic rocks in the Archaean terrane of the Barberton Mountain Land. This does not, however, imply that they are necessarily as volumetrically dominant as their surface area suggests. Field evidence indicates that the batholiths occur as relatively thin sheets over much of the earlier-formed crust and their development constituted one of the main events contributing to cratonization during and subsequent to which a measure of tectonic stability gradually prevailed in the early continental masses.

2. The Heerenveen and Mpuluzi batholiths, like their counterparts elsewhere in the Barberton Mountain Land, are multi-component bodies consisting of texturally and geochemically differing phases. Geochronologic and Sr-isotopic studies show that there is overlap on both the ages and initial ratios of the various phases indicating that they are isotopically indistinguishable and supporting the contention that they are all genetically linked. From their textural and spatial relationships it was established that the coarse porphyritic granites represent the oldest phase and constitute one component of a bimodal association — the other being a medium-fine-grained homogeneous granodiorite phase intrusive into the porphyritic phase in the form of small plutons and/or as an intricate network of dykes and veins. A third phase includes the medium grained pink or grey granodiorites and adamellites that are developed as a carapace over the coarser porphyritic granites and which are preserved in the high-lying areas on the batholiths. This phase,together with its feeder dykes,was formerly referred to as the Lochiel or Homogeneous Hood-type granite by Hunter (1973, 1974) and Viljoen and Viljoen (1969a, b). The fourth significant phase is that referred to as the marginal migmatite phase and is developed in the areas rimming the batholiths as well as in the low-lying terrane produced as a result of river incision in some regions. This is particularly the case with the Nelspruit batholith where migmatites and gneisses are exposed in the Crocodile and Sabie river valleys. In the south, however, neither the Mpuluzi nor the Great Usutu rivers have cut deep enough to expose the underlying basement to the Mpuluzi batholith.

   The marginal migmatites represent the products of interaction between the granitic components of the batholiths and components of the earlier crust into which these rocks were emplaced.

3. Geochemically the batholiths of the second magmatic cycle are distinct from the earlier soda-rich tonalite-trondhjemite gneisses in that they have greater K_2O and Rb contents. The chemical distinctions are best illustrated in Table 3 which demonstrates a progression in actual values of K_2O, Na_2O, Rb, and Sr from the earlier tonalites and trondhjemites through to the later Heerenveen, Nelspruit and Mpuluzi batholiths. The Heerenveen batholith shows some affinities with the trondhjemite end of the spectrum yet is clearly distinguishable chemically, structurally, texturally and isotopically from the latter. The Mpuluzi batholith is at the other extreme being a distinctively potash-rich body and the Nelspruit batholith has chemical characteristics intermediate between the two.

4. From petrogenetic modelling of the trace elements all three batholiths studied have Rb and Sr abundances that are compatible with the view that they were derived from the partial melting of tonalitic or trondhjemitic source rocks. The Mpuluzi batholith appears to be the result of the smallest degree of partial melting whereas the Heerenveen batholith was derived from the highest degree of partial melting. Conditions intermediate between these two end members resulted in the development of magmas responsible for the Nelspruit batholith.

5. In all three batholiths studied in the Barberton Mountain Land the trace element trends can be quantitatively modelled in terms of *in situ* crystal fractionation. In the case of the Heerenveen batholith crystal fractionation was governed by plagioclase + quartz, with K-feldspar being either "intercumulus" or late stage in character and hence responsible for the development of the poikilitic microcline megacrysts found in the body. With the Mpuluzi and Nelspruit batholiths,crystal fractionation appears to have been influenced by plagioclase + quartz + K-feldspar, with the potassic component being a liquidus phase during most of the crystallization or solidification history of these two bodies.

6. The theory of plate tectonics has provided an excellent framework for the evaluation of the differences in types and styles of igneous activity in terms of tectonic environment. Nowhere can the development of granitoid batholiths be more clearly linked to active plate boundaries and processes of subduction than in the Mesozoic plutonic complexes of the coast ranges of North and South America. According to Wyllie (1981), batholiths may include magmas derived by partial fusion of subducted oceanic crust, by partial fusion of mantle peridotite, and by partial fusion of deep-seated continental crust, together with differentiates of all these materials. The still dubious applicability of plate tectonic models to Precambrian (and particularly Archaean) crustal evolution is still a matter of considerable debate (Kröner, 1981). In view of the prevailing uncertainty it therefore appears that a choice has to be made between projecting the new global tectonics into the Archaeozoic, or resorting to some other petrologic mechanism,possibly unique to crustal evolution at this stage in the development of the earth.

   Despite careful appraisal of the rocks and their setting in the Barberton Mountain Land no satisfactory support has yet been mustered for a plate tectonic origin for all or even part of the region (Anhaeusser, 1981). In view of this, the model proposed by Robb *et al.* (1982) to explain the generation of the granitic magmas of the Nelspruit batholith is favoured here and the conclusions reached appear to be equally valid for the Heerenveen and Mpuluzi batholiths. This scheme envisages that approximately 3200-3000 Ma ago there followed a widespread de-gassing of volatiles derived from a deep-seated origin beneath the crust on the Kaapvaal craton. The upward migration of these volatiles produced widespread reduction in the solidus temperature of the tonalite/trondhjemite gneisses developed earlier during the first magmatic cycle. This resulted in extensive partial melting of the tonalites and trondhjemites and the generation of magma that progressively coalesced upwards to form the high-level, multi-component granitic phases of the second magmatic cycle batholiths (see also schematic diagram relating to the mode of origin and style of emplacement of the Nelspruit batholith depicted in Fig. 15 of Robb *et al.*, 1982).

ACKNOWLEDGMENTS

The authors wish to thank Drs. T.S. McCarthy and R.G. Cawthorn with whom useful discussions were held on various aspects relating to this study. In addition Mrs. L. Tyler, Mrs. D. Amaler and Mrs. W. Job are thanked for secretarial and draughting assistance.

REFERENCES

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

Anhaeusser, C.R. (1978). On an Archaean marundite occurrence (corundum-margarite rock) in the Barberton Mountain Land, Eastern Transvaal. *Trans. geol. Soc. S. Afr.*, 81, 211-218.

Anhaeusser, C.R. (1980). A geological investigation of the Archaean granite-greenstone terrane south of the Boesmanskop syenite pluton, Barberton Mountain Land. *Trans. geol. Soc. S. Afr.*, 83, 93-106.

Anhaeusser, C.R. (1981). Geotectonic evolution of the Archaean successions in the Barberton Mountain Land, South Africa, 137-160. In: A. Kröner, (Ed.), *Precambrian Plate Tectonics*, Elsevier, Amsterdam, 781 pp.

Anhaeusser, C.R. (1982). The geology of the Schapenburg greenstone remnant and surrounding Archaean granitic terrane south of Badplaas, Eastern Transvaal. *Spec. Publ. geol. Soc. S. Afr.*, (in press). also in : Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 158 (1981), 12 pp.

Anhaeusser, C.R., and Robb, L.J. (1980). Regional and detailed field and geochemical studies of Archaean, trondhjemite gneisses, migmatites and greenstone xenoliths in the southern part of the Barberton Mountain Land, South Africa. *Precambrian Res.*, 11, 373-397.

Anhaeusser, C.R., and Robb, L.J. (1981a). Magmatic cycles and the evolution of the Archaean granitic crust in the Eastern Transvaal and Swaziland. *Spec. Publ. geol. Soc. Aust.*, 7, (in press).

Anhaeusser, C.R., Robb, L.J., and Viljoen, M.J. (1981b). Provisional geological map of the Barberton greenstone belt and surrounding granitic terrane, Eastern Transvaal and Swaziland. 1:250 000 colour map, Geol. Soc. S. Afr.

Anhaeusser, C.R., Robb, L.J., and Barton, J.M. Jr. (1982). Mineralogy, petrology and origin of the Boesmanskop syeno-granitic complex, Barberton Mountain Land, South Africa. *Spec. Publ. geol. Soc. S. Afr.* (in press).

Barton, J.M. Jr. (1981). The pattern of Archaean crustal evolution for southern Africa as deduced from the evolution of the Limpopo Mobile Belt and the Barberton granite-greenstone terrane. *Spec. Publ. geol. Soc. Aust.*, 7, (in press).

Barton, J.M. Jr. (1982). Isotopic constraints on possible tectonic models for crustal evolution in the Barberton granite-greenstone terrane, southern Africa. *Spec. Publ. geol. Soc. S. Afr.* (in press).

Barton, J.M. Jr., Robb, L.J., Anhaeusser, C.R., and van Neirop, D.A. (1982). Geochronologic and Sr-isotopic studies of certain units in the Barberton granite-greenstone terrane, South Africa. *Spec. Publ. geol. Soc. S. Afr.* (in press).

Brown, G.C. (1970). A comment on the role of water in the partial fusion of crustal rocks. *Earth Planet. Sci. Lett.*, 9, 355-358.

Condie, K.C., and Hunter, D.R. (1976). Trace element geochemistry of Archean granitic rocks from the Barberton region, South Africa. *Earth Planet. Sci. Lett.*, 29, 389-400.

Davies, D.N. (1964). The tin deposits in Swaziland. In: Haughton, S.H. (Ed.), *The Geology of Some Ore Deposits in Southern Africa.* Geol. Soc. S. Afr., 2, 535-541.

Davies, R.D. (1971). *Geochronology and isotopic evolution of the early Precambrian crustal rocks in Swaziland.* Ph.D. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 135 pp.

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

Hamilton, P.J., Evensen, N.M., O'Nions, R.K., Smith, H.S., and Erlank, A.J. (1979). Sm-Nd dating of Onverwacht Group volcanics, southern Africa. *Nature,* 179, 298-300.

Hunter, D.R. (1970). The geology of the Usushwana Complex in Swaziland. *Spec. Publ. geol. Soc. S. Afr.*, 1, 645-660.

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

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

Kleeman, A.W. (1965). The origin of granitic magma. *J. geol. Soc. Aust.*, 12, 35-52.

Kröner, A., (Editor) (1981). *Precambrian Plate Tectonics*, Elsevier, Amsterdam, 781 pp.

Luth, W.C., Jahns, R.H., and Tuttle, O.F. (1964). The granite system at pressures of 4 to 10 kilobars. *J. Geophys. Res.*, 69, 759-773.

McCarthy, T.S., and Hasty, R.A. (1976). Trace element distribution patterns and their relationship to the crystallization of granitic melts. *Geochim. Cosmochim. Acta*, 40, 1351-1358.

McCarthy, T.S., and Robb, L.J. (1978). On the relationship between cumulus mineralogy and trace and alkali chemistry in an Archean granite from the Barberton region, South Africa. *Geochim. Cosmochim. Acta*, 42, 21-26.

Menell, R.P., Brewer, T.H., Delve, J.R., and Anhaeusser, C.R. (1981). The geology of the Kalkkloof chrysotile asbestos deposit and surrounding area, Barberton Mountain Land. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand*, 154, 10 pp.

Neumann, H., Mead, J., and Vitaliano, C.J. (1954). Trace element variation during fractional crystallization as calculated from the distribution law. *Geochim. Cosmochim. Acta*, 6, 90-99.

Oosthuyzen, E.J. (1970). *The geochronology of a suite of rocks from the granite terrain surrounding the Barberton Mountain Land.* Ph.D. thesis (unpubl.), Univ. Witwatersrand, Johannesburg.

Pitcher, W.S. (1979). The nature, ascent and emplacement of granitic magmas. *J. geol. Soc. Lond.*, 135, 627-662.

Robb, L.J. (1977). *The geology and geochemistry of the Archaean granite-greenstone terrane between Nelspruit and Bushbuckridge, Eastern Transvaal.* M.Sc. thesis (unpubl.), Univ. Witwatersrand, Johannesburg 190 pp.

Robb, L.J. (1978). A general geological description of the Archaean granitic terrane between Nelspruit and Bushbuckridge, Eastern Transvaal. *Trans. geol. Soc. S. Afr.*, 81, 331-338.

Robb, L.J. (1981a). Detailed studies of select migmatite outcrops in the region southwest of the Barberton greenstone belt and their significance concerning the nature of the early Archaean crust in the region. *Spec. Publ. geol. Soc. Aust.*, 7, (in press).

Robb, L.J. (1981b). *The geological and geochemical evolution of tonalite-trondhjemite gneisses and migmatites in the Barberton region, eastern Transvaal.* Ph.D. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 342 pp.

Robb, L.J. (1981c). Geological and chemical characteristics of late granite plutons in the Barberton region and Swaziland with an emphasis on the Dalmein pluton — a review. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg*, 157, 16 pp.

Robb, L.J. (1982). The nature, origin and significance of Archaean migmatites in the Barberton Mountain Land; a new approach in the assessment of early crustal evolution. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Robb, L.J., and Anhaeusser, C.R. (1982). Chemical and petrogenetic characteristics of Archaean tonalite-trondhjemite gneiss plutons in the Barberton Mountain Land. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Robb, L.J., Anhaeusser, C.R., and van Nierop, D.A. (1982). The recognition of the Nelspruit batholith north of the Barberton greenstone belt and its significance in terms of Archaean crustal evolution. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Schwerdtner, W.M., and Lumbers, S.B. (1980). Major diapiric structures in the Superior and Grenville provinces of the Canadian Shield. *Spec. Pap. geol. Assoc. Can.*, 20, 149-180.

Shaw, D.M. (1970). Trace element fractionation during anatexis. *Geochim. Cosmochim. Acta*, 34, 237-243.

Viljoen, M.J., and Viljoen, R.P. (1969a). The geochemical evolution of the granitic rocks of the Barberton region. *Spec. Publ. geol. Soc. S. Afr.*, 2, 189-219.

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

Viljoen, M.J., and Viljoen, R.P. (1969c). 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.

von Platen, H. (1965). Experimental anatexis and genesis of migmatites, 203-218. In: Pitcher, W.S. and Flinn, G.W., Eds., *Controls of Metamorphism*, Oliver and Boyd, London, 368 pp.

Winter, T.E. (1962). The Usushwana Complex. *Spec. Rep. Geol. Surv. Swaziland*, 4, 30 pp.

Wyllie, P.J. (1981). Plate tectonics and magma genesis. *Geol. Rundsch.*, 70, 128-153.

oOo

APPENDIX

Part 1. Trace Element Contents of Envisaged Parental Magmas for the Mpuluzi and Heerenveen Batholiths

The parental magmas to the Mpuluzi and Heerenveen batholiths are considered to have been derived by different degrees of partial melting of a tonalitic source comprising 55% plagioclase : 35% quartz : 5% biotite : 5% K-feldspar.

The bulk partition coefficients (D) for Rb, Sr and Ba with respect to the above assemblage are :-

D_{Rb} - 0,22
D_{Sr} - 1,76
D_{Ba} - 0,83

The trace element contents of this tonalite parent are considered to be :-

Rb - 60 ppm
Sr - 1000 ppm
Ba - 375 ppm

(i) Mpuluzi magma is derived by 20% partial melting of the above tonalite. Using the batch melt equations of Shaw (1970) the trace element contents of this melt are :-

Rb - 170 ppm
Sr - 664 ppm
Ba - 586 ppm

(ii) Heerenveen magma is derived in a similar manner but by a 70% partial melt of the same tonalitic parent. Its trace element contents, therefore, are :-

Rb - 81 ppm
Sr - 833 ppm
Ba - 356 ppm

Part 2. Trace Element Variations in Terms of Crystal Fractionation in the Mpuluzi and Heerenveen Batholiths

(i) Mpuluzi batholith

The sequence of crystallization in this body is envisaged as follows :-

Initial 15% of crystallization with 55% plagioclase : 40% quartz : 5% biotite on the liquidus.
Subsequent 85% of crystallization with 46% plagioclase : 25% quartz : 25% K-feldspar : 4% biotite on the liquidus.

The bulk partition coefficients of these two assemblages are :-

First 15%	Subsequent 85%
D_{Rb} = 0,19	D_{Rb} = 0,33
D_{Sr} = 1,57	D_{Sr} = 2,28
D_{Ba} = 0,52	D_{Ba} = 1,95

Using the fractional crystallization equations of Newman *et al.* (1954) and the relevant parental magma abundances calculated in Part 1 of the Appendix, the trace element contents of solid (C_s) and residual liquid (C_l) for various crystallization increments (F) are given as :-

	C_s			C_l		
F	Rb	Sr	Ba	Rb	Sr	Ba
5%	34	1012	312	177	645	600
10%	35	982	320	185	625	616
15%	37	950	329	194	605	633
18%	64	1174	946	194	515	485
25%	68	1047	869	206	459	446
50%	89	623	591	270	273	303
75%	142	257	306	430	113	157
85%	200	133	188	606	58	97

(ii) Heerenveen batholith

The sequence of crystallization in this body is envisaged as follows :-

Initial 75% of crystallization with 63% plagioclase : 30% quartz : 7% biotite on the liquidus.
Subsequent 25% of crystallization with 48% plagioclase : 25% quartz : 23% K-feldspar : 4% biotite on the liquidus.

The bulk partition coefficients of these two assemblages are :-

First 15%		Subsequent 85%	
D_{Rb}	= 0,26	D_{Rb}	= 0,31
D_{Sr}	= 1,80	D_{Sr}	= 2,26
D_{Ba}	= 0,68	D_{Ba}	= 2,01

Using the fractional crystallization equations of Newman *et al.* (1954) and the relevant parental magma abundances calculated in Part 1 of the Appendix, the trace element contents of solid (C_s) and residual liquid (C_l) for various crystallization increments (F) are given as :-

	C_s			C_l		
F	Rb	Sr	Ba	Rb	Sr	Ba
10%	23	1378	150	88	766	368
25%	26	1191	265	100	661	390
50%	35	861	302	135	478	444
76%	59	494	377	225	274	555
77%	69	295	162	223	131	81
85%	93	172	107	300	76	53
90%	123	103	70	396	46	35

oOo

PLATE 1

Aerial photograph of part of the Heerenveen batholith showing the degree of exposure and the nature of the Proterozoic diabase dyke swarm. Most of the dykes are aligned in a NW-SE direction parallel to a prominent fracture pattern that occurs throughout the region south of the Barberton greenstone belt. Some diabase dykes trend in a NE-SW direction whereas a few Karoo dolerite dykes (like the one seen on the left of the photograph) have a north-south orientation.

PLATE 2

A. Large megacrysts of microcline in a coarse-grained phase from the central part of the Heerenveen batholith on the farm Heerenveen 27IT.

B. Isolated, large microcline megacryst in coarse porphyritic, high alkali trondhjemite from the Heerenveen batholith. Sample locality on the farm Ida 144 IT.

C. Coarse, intensely porphyritic phase of the Heerenveen batholith on the farm Kleinbuffelspruit 32IT. Shown in the photograph are large, positively weathering quartz megacrysts in a negative matrix consisting mainly of plagioclase, microcline and some biotite.

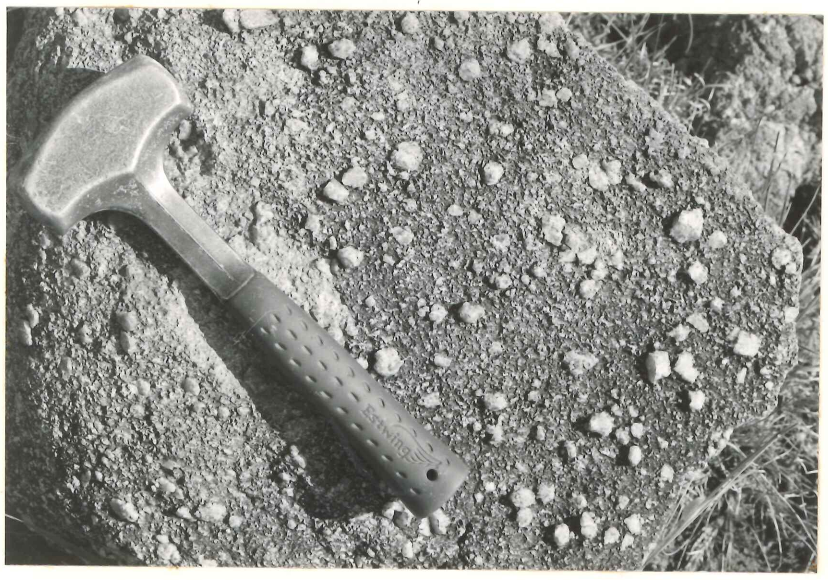
D. Veins of medium-fine-grained granodiorite intruding the coarse porphyritic phase of the Heerenveen batholith on the farm Heerenveen 27IT. The two phases constitute what is referred to as the bimodal association and are remarkably similar to the veins of Hebron granodiorite that intrude the Nelspruit porphyritic granite north of the Barberton greenstone belt (see Robb, 1978 and Robb *et al.*, 1982).

E. Banded migmatites in the marginal migmatite zone on the eastern flank of the Heerenveen batholith. The darker zones are altered greenstone xenoliths aligned parallel to the western contact of the Schapenburg greenstone remnant described by Anhaeusser (1982). The light coloured bands consist of trondhjemitic gneisses, the latter partly or totally altered to granodiorites in the aureole surrounding the Heerenveen batholith.

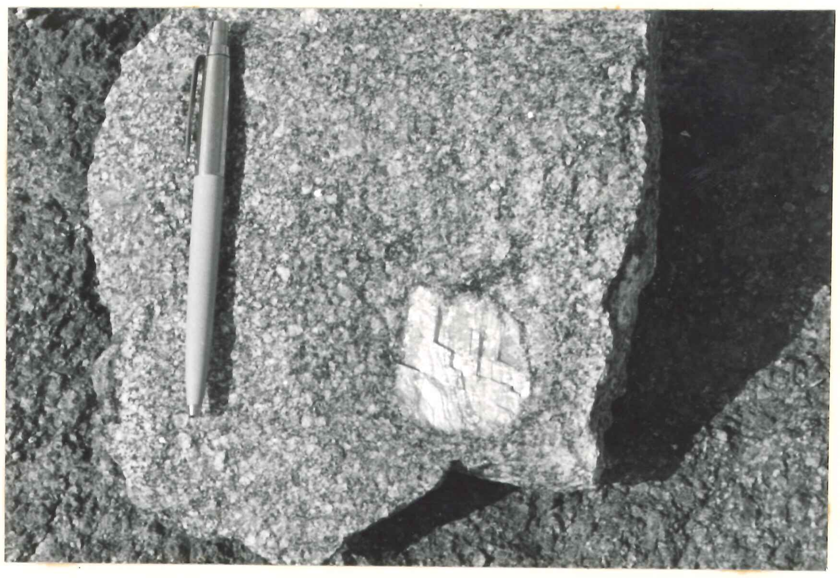
F. View, looking south, of the prominent cliffs forming the northern rim of the Mpuluzi batholith on the farms Welgevonden 175IT and Welverdiend 174IT. In the foreground, and occupying the topographical low-lying grasslands, are greenstone xenoliths and trondhjemitic gneisses forming part of the first magmatic cycle as defined by Anhaeusser and Robb (1981).

PLATE 2

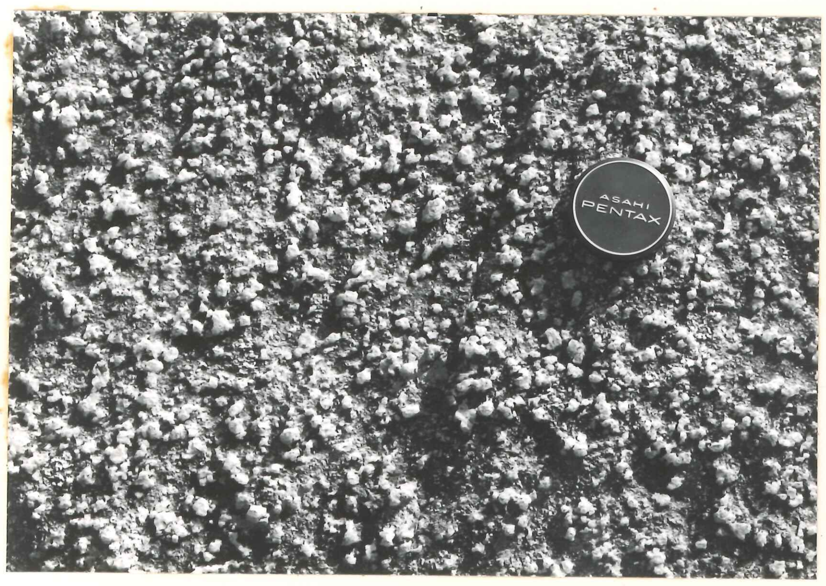
A



B



C



D

E

F

PLATE 3

A. View looking east (from the farm Northdene 247IT situated approximately 5 km from Bell's Kop trigonometrical beacon on the Swaziland border) of the central part of the Mpuluzi batholith. The porphyritic adamellites are well-exposed in tors and exfoliated domical outcrops throughout the catchment area of the Mpuluzi and Great Usutu rivers.

B. View, looking north-west, down one of the many V-shaped valleys located on the northern rim of the Mpuluzi batholith. The courses of many of the streams developed on the batholith are influenced by the NW-SE trending fractures and dykes cutting across the granite massif.

C. Banded migmatites and gneisses cut by veins and dykes of pegmatite and medium-to-coarse-grained granodiorite in the marginal migmatite zone rimming the Mpuluzi batholith. The banded migmatites are exposed in a river near the Oshoek border post (on the farm Oshoek 212IT) and represent the altered remnants of the southern extension of the Barberton greenstone belt.

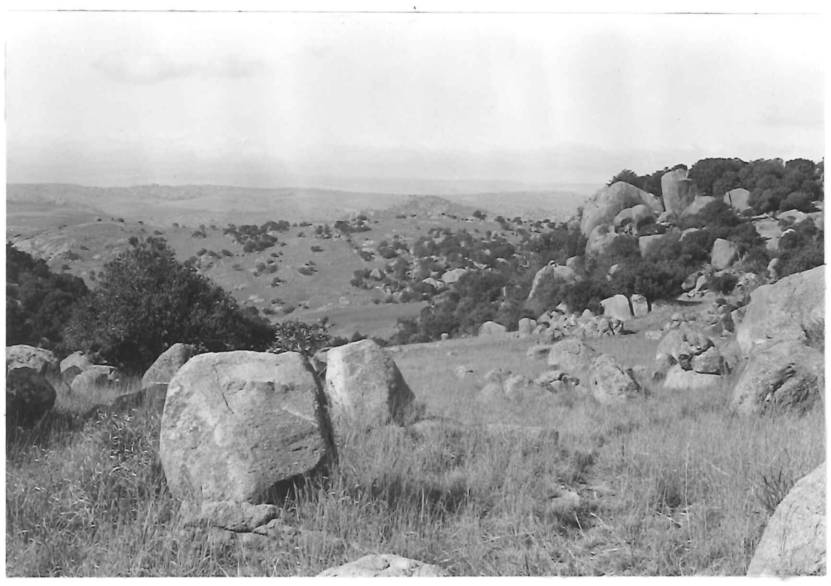
D. Foliated trondhjemitic gneiss cut by pegmatite dykes and veins associated with the Mpuluzi batholith. The foliated gneisses represent remnants of first magmatic cycle rocks preserved in the marginal migmatite zone located on the farm Houtbosch 189IT, south of the Steynsdorp pluton. At this locality the gneisses are orientated at right angles to the northern rim of the Mpuluzi batholith. Pegmatites found in the area have been prospected for tin mineralization (cassiterite).

E. Foliated trondhjemitic gneisses developed in the marginal migmatite zone of the Mpuluzi batholith on the farm Houtbosch 189IT, south of the Steynsdorp pluton. The gneisses are cut by a stockwork of pegmatites and ultimately become engulfed by the potassic granites as the main Mpuluzi massif is approached.

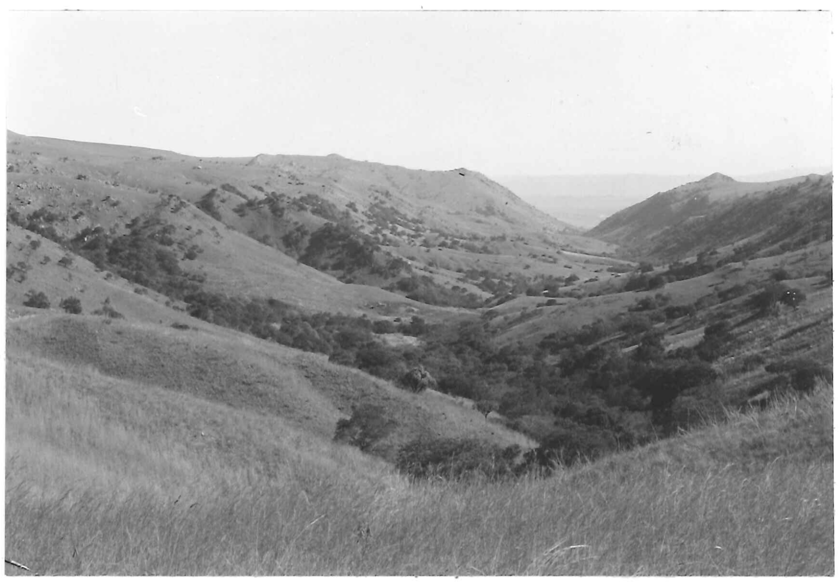
F. Porphyritic dark grey gneiss, containing hornblende and K-feldspar porphyroblasts, in the marginal migmatite zone of the Mpuluzi batholith (quarry exposure on the Mpuluzi River on the farm Caledonia 97IT). The melanocratic rocks are developed in the batholith aureole close to the eastern contact of the Schapenburg greenstone remnant and are cut by pegmatites and homogeneous Hood-type granodiorites.

PLATE 3

A



B



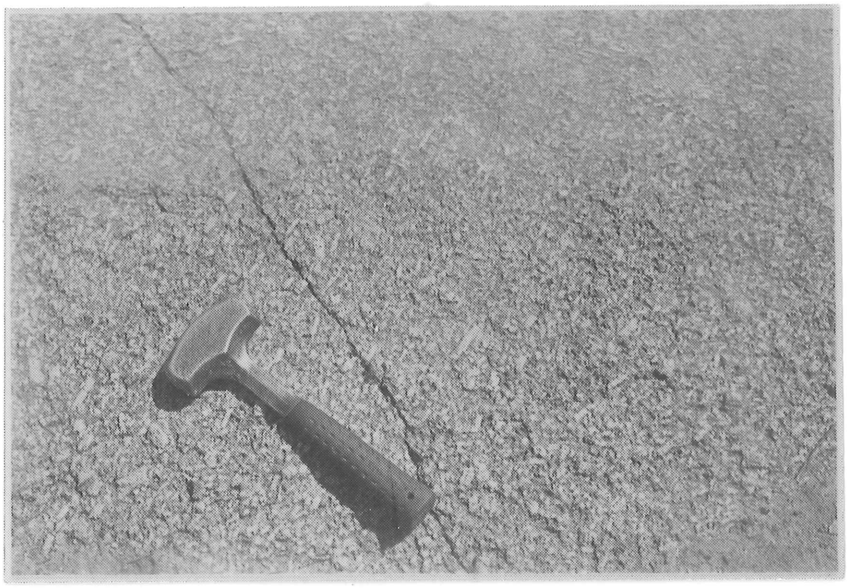
C

D

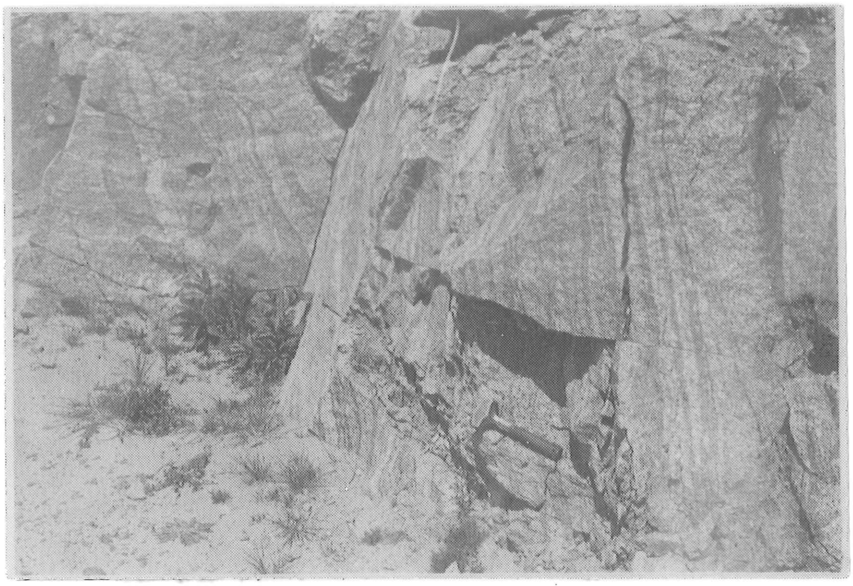
E

F

PLATE 4



A. Porphyritic, pinkish, massive and homogeneous adamellite from the central part of the Mpuluzi batholith on the farm The Gem 231IT. The K-feldspar megacrysts are locally well-aligned but no systematic orientation could be determined regionally.



B. Nebulitic granites exposed in a road cutting in the central part of the Mpuluzi batholith (on the farm Damesfontein 226IT). The ghost-remnants, comprised of a dark grey biotite-rich granodiorite phase in a pinkish-grey coarse-grained adamellite phase, could either represent altered greenstone material or an altered dyke, the latter possibly intruded into the Mpuluzi batholith at an early stage of its emplacement.