ECONOMIC GEOLOGY RESEARCH UNIT

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THE GRANITIC ROCKS OF THE PRECAMBRIAN IN SWAZILAND

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INFORMATION CIRCULAR No. 63

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August, 1971

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(for Restricted Distribution)

The information contained herein has been submitted for publication and represents a contribution to the "Granite 71" Symposium arranged by the Rhodesian Branch of the Geological Society of South Africa, to be held in Salisbury, Rhodesia, during August/September, 1971.

THE GRANITIC ROCKS OF THE PRECAMBRIAN IN SWAZILAND

ABSTRACT

The granitic rocks are subdivided into (1) the Ancient Gneiss Complex which includes the widespread tonalitic gneisses and migmatites, (2) the Tonalite Gneiss Domes, (3) the Granodiorite Suite, (4) the Nelspruit Migmatites and Gneisses, (5) the Homogeneous Hood Granite and (6) the Granite Plutons. The petrological terminology applied to the acid plutonic rocks is based on the system of Harpum (1963).

It is concluded that the tonalitic gneisses were derived by *in situ* granitization of volcanic and sedimentary rocks which had suffered metamorphism of Abukuma type to the cordierite-amphibolite facies. Doubt exists as to age relationship between these metamorphites and the Swaziland Sequence but it is provisionally suggested that the metamorphites pre-date the Swaziland Sequence.

Following the deposition, and accompanying the deformation of the Swaziland Sequence the Ancient Gneiss Complex basement was re-activated to give the tonalitic diapir domes which are confined to the western and southern flanks of the Swaziland Sequence outcrop. The Granodiorite Suite consists of predominantly leuco-tonalitic and trondhjemitic rocks with more basic differentiates. Its relation to the Swaziland Sequence is not known, but it is suggested that the Suite was emplaced at some time during the deformation of the Swaziland Sequence.

The Homogeneous Hood Granite, which represents a major period of potassium accretion to the crust at about 3,000 m.y., intrudes both the Swaziland and Pongola Sequences. The granite grades from the underlying Ancient Gneiss Complex through a zone of migmatites to form sheet-like bodies.

The final granitic event was the emplacement of transgressive plutons. An early series of plutons of granodioritic composition is recognized in the Transvaal. In Swaziland two ages can be demonstrated but the plutons of both ages are composed of potash-rich granites.

The tectonic setting of the granitic rocks is discussed. A distinction is drawn between the tectonic styles of granitic rocks emplaced in orogenic zones and the apparently non-orogenic Homogeneous Hood Granites and Granite Plutons.

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THE GRANITIC ROCKS OF THE PRECAMBRIAN IN SWAZILAND

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INTRODUCTION

The correlation of the earliest Precambrian sedimentary and volcanic sequences was based in the past largely on similarities in lithology, degree of metamorphism and deformation, and stratigraphic succession, as it was not found possible to extend to these formations the classic principles of Phanerozoic stratigraphy. With the development of isotopic age determination techniques an additional tool was provided. Age measurements are usually made on volcanic or plutonic rocks, or minerals from these rocks, occurring in association with the sedimentary formations. The greater proportion of the rocks available for age measurements in the Precambrian terrains are granitic in composition.

The use of age determinations becomes meaningful only if the sequence of events recorded in these granitic rocks is fully understood. Swaziland and the adjacent areas of the Transvaal have provided a wealth of information on the earliest Precambrian (Viljoen and Viljoen, 1969a and b). The greenstone/sedimentary sequence is well preserved and the enveloping granitic rocks are exposed both laterally and vertically. The fact that these conditions prevail is reflected in the number of papers which have been published. Those dealing with the granitic rocks include Hall, 1918; van Eeden, 1941; Hunter, 1957, 1965, 1968, and 1970; van Eeden and Marshall, 1965; Anhaeusser, 1966; Roering, 1967; Anhaeusser et al, 1968 and 1969; and Viljoen and Viljoen, 1969a and b. Isotopic age measurements on granitic and other rocks have been reported by Allsopp et al, 1962, 1968 and 1969; de Gasparis, 1967; van Niekerk and Burger, 1967; and Oosthuyzen, 1969.

In younger Precambrian and other granite terrains it has been found useful to apply a geotectonic classification to the granitic rocks. Although attempts have been made to employ such techniques in Swaziland (Hunter, 1957 and 1965) they have encountered serious difficulties as criteria used in many classic investigations are not entirely applicable. In view of the fact that large areas of the African shield are underlain by granitic rocks it is considered that a geotectonic classification is necessary. It is well known that granitic rocks have a style distinctive of their setting in space and time, and that repetition of these styles occurs during times when the appropriate physical conditions recur.

The terminology currently applied to the acid plutonic rocks is often confusing and it is necessary to define the meanings of the terms used. In Swaziland the terminology proposed by Harpum (1963) has been adopted. Harpum (1963), using Nockolds' (1954) average analyses, established a subdivision of the granitic rocks based on their $K_2O:Na_2O$ ratio and silica content. This scheme is considered to be of value because it was found that there is, in general terms, a progression from older, sodic to younger, potassic types. It must, however, be emphasized that there is not a simple progression.

GEOLOGICAL SETTING

Granitic rocks in Swaziland and the eastern Transvaal envelop an approximately triangular area, having a long axis of 115 km and a base of 55 km, underlain by volcanic and sedimentary rocks of the Swaziland Sequence. The Swaziland Sequence (with a thickness of at least 21,000 metres) has been strongly deformed about dominant east-northeast-trending axes. It has suffered low-grade, regional, greenschist metamorphism but within the core of the outcrop area even this grade of metamorphism is not reached. A very narrow aureole of upper greenschist to amphibolite and granulite facies is found along the granite contacts.

In southern Swaziland cratonic-type sedimentary and volcanic rocks ascribed to the Pongola Sequence crop out. The basal Insuzi Group is predominantly volcanic consisting of andesites and felsites with a single, originally argillaceous zone developed in Swaziland. The prominent basal quartzite which is found in the Transvaal is preserved in Swaziland only as a small xenolith within the gabbro-microgranite sheet that lies at the base of the Insuzi Group. The Mozaan Group consists of alternating arenaceous and argillaceous sediments, the former being predominant in the lower portion. Low-grade (greenschist) regional metamorphism affects these rocks.

The granitic rocks intruding the Swaziland and Pongola Sequences range in composition from tonalite through granodiorite and adamellite to granite. In the central area of Swaziland relict bodies of metamorphites crop out concordantly with migmatitic gneisses and more homogeneous grey tonalitic gneisses. This assemblage has been called the Ancient Gneiss Complex (Hunter, 1965, 1968) and has recently been described in detail (Hunter, 1970).

Along the southwestern and western margins of the Swaziland Sequence tonalite intrudes the Onverwacht Group (the basal member of the Swaziland Sequence) in the form of a number of gneiss domes or diapirs (Viljoen and Viljoen, 1969a). Their equivalents are not found in Swaziland.

A differentiated series of plutonic rocks builds one major and two minor elongate bodies in Swaziland. The term Granodiorite Suite has been applied to these rocks (Hunter, 1965, 1968). The rock types falling within this suite range from hornblendite and peridotite through gabbro, quartz gabbro and quartz diorite to tonalite and granodiorite. This group is not apparently represented in the Transvaal.

The Homogeneous Hood Granite builds the high ground forming the Swaziland highveld. This granite can be seen to grade down through a complex migmatite zone into the Ancient Gneiss Complex. On the Transvaal side erosion has removed the bulk of the homogeneous granite (except in the southwest) and only the migmatite zone is preserved. This constitutes the Nelspruit Gneisses and Migmatites (Viljoen and Viljoen, 1969a).

The last granitic event resulted in the emplacement of randomly oriented coarse-grained, usually porphyritic plutons. Both in Swaziland and the Transvaal at least two ages of pluton emplacement are recognized.

In a recent review of the granitic rocks of the Swaziland-Transvaal area, Viljoen and Viljoen (1969a and b) have proposed the incorporation of the Granodiorite Suite within their Ancient Tonalite Gneisses, which they postulate represents a widely generated tonalitic magma derived during a major differentiation episode within the upper mantle, post-dating the Swaziland Sequence. Viljoen and Viljoen suggest that this magma was "a complementary response to the immediately preceeding vast outpouring of largely 'primitive' mafic and ultramafic lavas (komatiite), all singularly devoid of alkalies and other lithophile elements". The same authors regard many of the metamorphic relicts within the Swaziland Ancient Gneiss Complex as being remnants of the basal Swaziland Sequence. Viljoen and Viljoen consider that the Ancient Gneiss Complex of Swaziland consists of remnants of the basal portion of the Swaziland Sequence intruded by tonalitic magma, the latter being their Ancient Tonalitic Gneisses.

The classification of the granites by Viljoen and Viljoen is compared in the following tabulation with that adopted in Swaziland :

Viljoen and Viljoen 1969a	Hunter (this paper)
D. The Young Plutons	6. The Granite Plutons
C. The Nelspruit Gneisses and Migmatites	5. The Homogeneous Hood Granite
B. The Homogeneous Hood Granite	4. The Nelspruit Gneisses and Migmatites
A. The Ancient Tonalite Gneisses	3. The Tonalite Gneiss Domes
	2. The Granodiorite Suite
	1. The Ancient Gneiss Complex

The absence of tonalitic gneiss domes in Swaziland and of the Granodiorite Suite in the Transvaal renders it impossible to give relative ages for these two groups. It is possible that they may be largely contemporaneous.

THE GRANITIC ROCKS

A. THE ANCIENT GNEISS COMPLEX

This term was introduced to cover a complex suite of metasedimentary rocks, paragneisses, amphibolites, various pyroxene-bearing gneisses and granulites, and serpentinites, all of which are intimately associated with widespread tonalitic gneisses and migmatites. The Complex has been described in detail in a recent publication (Hunter, 1970) and only the main conclusions will be repeated here.

The following rock types occur as remnants within the tonalitic gneisses and migmatites :

(a) Quartzites and quartzofeldspathic gneisses

(b) Ironstones

(c) Cummingtonite and anthophyllite-cordierite gneisses

(d) Cordierite-bearing gneisses (including kinzigites)

(e) Siliceous and biotite-rich garnetiferous gneisses

(f) Quartz-diopside and diopside-plagioclase granulites

(g) Biotite and biotite-hornblende gneisses

(h) Amphibolites

(i) Quartz-biotite-hornblende-diopside gneisses

(j) Ultramafic rocks

Of the above rock types, quartzofeldspathic gneisses are most common north of Hlatikulu, where they are interlayered with siliceous garnetiferous gneisses. Outcrops of quartzite, kinzigite and cordierite-bearing gneisses, and quartz-biotite-hornblende-diopside gneisses are confined to the Mkhondo valley. Amphibolites are ubiquitous throughout the Ancient Gneiss terrain. The biotite and biotite-hornblende gneisses, although common, are usually extensively migmatitized. Ultramafic rocks (serpentinites) are rare, being located within some of the larger bodies of amphibolite.

The mineral assemblages of the resister rocks are in general terms, as follows :

(i) Amphibolites : plagioclase (oligoclase/andesine)-hornblende-diopside

(ii) Ultramafic rocks : tremolite-magnetite; actinolite-magnetite; chrysotile-tremolite-talc-chlorite

(iii) Biotite-rich gneisses : garnet (almandine)-biotite-quartz; biotite-cordierite-almandine-quartz; biotite-cordierite-almandine-quartz-microcline

(iv) Diopside granulites : diopside-plagioclase-quartz; diopside-plagioclase; quartz-diopside-(plagioclase)

(v) Ironstones : quartz-hypersthene-grunerite-garnet-magnetite; quartz-grunerite-garnet-magnetite

(vi) Magnesia-rich rocks : anthophyllite-biotite-cordierite-quartz; cummingtonite-cordierite-quartz

It is concluded that, before granitization, the Ancient Gneiss Complex was subjected to regional metamorphism in the higher grades of the cordierite-amphibolite facies (Winkler, 1957).

The tonalitic gneisses are generally foliated rocks with a prominent compositional banding, the fabrics of which are parallel to the foliation of the resister rocks. The tonalitic gneisses display none of the classical phenomena indicative of intrusive contacts such as apophyses, dykes and chilled margins. Bands of tonalitic gneiss range from a few millimetres to several tens of metres in width. All gradations can be observed from migmatites in which the host rock can be identified through gneisses in which the loss of original structures indicates that granitization has reached a more advanced state to homogeneous gneissic tonalite.

With the appearance of feldspars in the migmatites, there is a sympathetic development of an apparently retrogressive mineral assemblage. Thus hornblende alters to hornblende + biotite + epidote which assemblage in turn is altered to biotite + chlorite + epidote. These changes are accompanied by the destruction of the original gneiss texture and by the appearance of an increasing amount of feldspar. The changes could be attributed to retrograde metamorphism but this is not consistent with the field evidence which indicates that these changes become more marked as the degree of feldspathization increases and the proximity to bands of tonalitic gneiss decreases. The importance of the rôle of water as a free phase has been demonstrated by Yoder

(1955) and it is considered that aqueous solutions have played a rôle in the production of the retrograde mineral assemblage accompanying the granitization.

The tonalitic gneisses are composed of quartz, feldspar, biotite and hornblende, the proportions of each varying with the degree of homogenization. In the more leucocratic tonalitic gneisses hornblende is rare or absent, and microcline is more abundant although it is always subordinate to plagioclase.

Southeast of Mankaiana darker coloured, hornblende tonalite gneisses crop out. These were formerly believed to be of a different age from the other gneisses (Hunter, 1957) but their structural conformity and intimate association with the more typical tonalitic gneisses is taken as evidence that they form an integral part of the Ancient Gneiss Complex.

Subsequent to its metamorphism, the Ancient Gneiss Complex was granitized. Four possible origins have been considered for the tonalitic gneisses and migmatites, namely :

(a) differentiation in a solidifying magma chamber,

(b) lit-par-lit intrusion of magma,

(c) metamorphic differentiation of originally homogeneous or heterogeneous rocks, and

(d) *in situ* replacement by either (i) dry or (ii) wet diffusion.

The presence of mafic bands with 50 per cent SiO_2 alternating with quartzofeldspathic rocks with 70 to 80 per cent SiO_2 is unlikely to have resulted from primary banding in a plutonic mass. The possibility of lit-par-lit intrusion by a tonalitic magma is considered unlikely because

(a) there would be a very large volume increase which could be expected to produce a large horizontal component in steeply dipping rocks and hence large-scale deformation;

(b) the viscosity of acid magma would seemingly preclude the delicate injection observed in the migmatitic gneisses;

(c) the structural conformity of the resister rocks with the tonalitic gneisses, particularly the large amphibolite bands which are traceable for up to 8 km along strike, throughout which distances they display no sign of having been invaded by a magma.

The hypothesis that the observed layering results wholly from metamorphic differentiation is not supported by the fact that the original bedded sequence is preserved in some places, particularly in the Mkhondo valley.

The field evidence, therefore, does not support the first three postulated origins. There remains the possibility that the tonalitic gneisses and migmatites were formed by granitization *in situ*. Dry diffusion is rejected on the grounds that, at the presently known rates of diffusion, it would require an extremely long period of time to convert the original rock sequence in an area of several hundreds of square kilometres, even allowing for the elevated temperatures that must have prevailed.

Superheated aqueous solutions migrating through the Ancient Gneisses, producing apparently retrogressive mineral changes in the metamorphic rocks, are believed to provide the means whereby the tonalitic gneisses and migmatites were formed.

Circumstantial evidence points to the conclusion that the metamorphism and granitization of the Ancient Gneisses pre-dates the Swaziland Sequence. Certain mafic dyke-like bodies have been observed in the gneisses. The absence of any diagnostic features establishing that these dykes represent a period of mafic dyking under brittle crustal conditions precludes the definite assumption that they indicate a significant time-break between the Ancient Gneiss Complex and the Swaziland Sequence. Mafic dykes are found which were emplaced prior to granitization, but the possibility cannot be excluded that they represent original lamprophyric dykes the presence of which would not necessarily be indicative of a distinctive period of dyking (vide, Sederholm, 1926, p. 35).

B. THE GRANODIORITE SUITE

Coarse-grained, plutonic rocks, ranging in composition from ultramafic to acidic crop out in elongate bodies at Skombeni and Sitobela, and in the Mkhondo Valley in the middle- and lowveld areas of Swaziland. In order to arrive at an estimation of the proportions of the constituents of the suite, a planimetric determination of their areal extent was made from 1:50,000 scale geological sheets. The figures can be regarded only as approximate because of the difficulty in poorly exposed country of defining boundaries. The following proportions were obtained :

(i)	Ultramafic rocks	0.5%
(ii)	Gabbro, quartz gabbro and quartz diorite	25.0%
(iii)	Tonalite	60.5%
(iv)	Mliba granodiorite	14.0%

(a) Skombeni

The largest area underlain by the Granodiorite Suite extends in a general northeasterly to east-northeasterly direction from the Usutu River to the Mbuluzi River, a distance of 50 km. The maximum breadth of outcrop is 20 km. Along the southern termination and part of the western margin younger, granite plutons intrude the Suite, which itself is intrusive into the Ancient Gneiss Complex along its eastern boundary and part of its western boundary.

At the northeastern end a small pluton, the Mliba granodiorite, gives rise to a distinctive topography of large rectangular tors. The granodiorite has petrological and chemical similarities with the more acid members of the Granodiorite Suite and has been correlated with this group. In contradistinction to the other members of the Granodiorite Suite, the Mliba granodiorite has transgressive contacts with the Ancient Gneiss Complex although the slight elongation of the pluton is parallel to the general regional strike of the foliation in the Ancient Gneiss Complex.

The more basic members of the Granodiorite Suite in this area are medium- to coarse-grained, hornblendites and peridotites, cropping out as a series of small xenoliths in tonalite north and northwest of Manzini. The peridotites are composed of olivine and actinolite or hornblende. The hornblendites are composed of hornblende pleochroic in shades of pale green, brown or greenish brown. Sometimes colourless diopsidic augite is present and interstitial plagioclase (An_{54}) may also occur.

Quartz diorite and diorite underlie most of the southern portion of the Skombeni body. They are medium- to coarse-grained massive rocks without any well defined planar fabric. The diorites are composed of plagioclase (andesine), usually saussuritized, chloritized biotite and some ragged hornblende laths. Interstitial quartz is present in the more siliceous varieties. In rapids along the Usushwana River are exposed fresh outcrops of dark, coarse-grained rocks of quartz-dioritic appearance. They are composed of plagioclase, microcline, biotite, hornblende, diopside and quartz in that order of abundance, each mineral being fresh and unaltered.

The northern portion of the Skombeni occurrence is composed of tonalite. Typically these rocks are pale coloured and coarse-grained but in the vicinity of basic or ultrabasic xenoliths they become darker in colour. The tonalites are composed essentially of plagioclase and quartz with lesser and variable amounts of biotite, hornblende and microcline. The biotite is present as ragged chloritized wisps. Hornblende, which is present in the tonalites adjacent to basic xenoliths or transitional into quartz diorites, is a bluish green variety. Microcline is always interstitial and is present only in the more acid tonalites.

The Mliba granodiorite is a coarse-grained, slightly porphyritic, pale coloured rock, composed of quartz, plagioclase, and microcline with ragged wisps of chloritized biotite. Whereas the plagioclase is typically saussuritized, the microcline is fresh. It is perthitic and regular cross-hatching is typical. Allanite, epidote, zircon and apatite are present as accessory minerals.

(b) Sitobela

This outcrop of the Granodiorite Suite is well-exposed only at its southern end where it intrudes members of the Ancient Gneiss Complex. Along the whole of the western boundary a younger granite pluton is intrusive, while on the east the Karroo Sequence overlaps onto the members of the Suite. The outcrop area occupies 160 square km.

TABLE 1

MINERALOGICAL DATA : GRANODIORITE SUITE

	Peridotite	Hornblendite	Gabbro	Quartz Diorite	Tonalite	Granodiorite
Microcline	-	-	-	Present only in hybrid variety	Present in variable amounts from 2 to 10 per cent	Perthitic micro-cline present in amounts of between 18 and 20 per cent
Plagioclase	Interstitially developed at margins of some peridotites An_{54}	-	Labradorite An_{54} Nm = 1.560	Andesine Nm = 1.548	Oligoclase An_{24} Nm = 1.543 2V = 76°-86° (+) Present up to 65 per cent	Oligoclase Nm = 1.542 2V = 87° (+)
Amphibole	Brownish green hornblende 2V = 80, Z∧c = 20° or pale green actinolitic hornblende 2V = 78, Z∧c = 24°	Brown hornblende 2V = 80° Z∧c = 20 Nm = 1.665	Brownish green hornblende 2V = 78° Z∧c = 19°	Bluish green hornblende 2V = 79° Z∧c = 22° Nm = 1.673	Bluish green hornblende 2V = 77° Z∧c = 21° Present in amounts up to 8 per cent in contaminated tonalites	absent
Pyroxene		Diopsidic augite 2V = 60° Z∧c = 44° Nm = 1.708	Hypersthene 2V = 50°-55° Nm = 1.710 Diopsidic augite 2V = 58° Z∧c = 42°	Usually present only as residual cores, but in hybrid type fresh and unaltered	absent	absent
Biotite			Red-brown Nm = 1.660	Red-brown or brown Nm = 1.660 but in leuco-tonalites usually chloritized	Chloritized green biotite as ragged wisps	Chloritized green biotite as ragged wisps
Olivine	Fa_{10} 2V = 89° Nm = 1.681	absent	absent	absent	absent	absent

Hornblende- and biotite-bearing tonalites are the most common rock types but towards the Usutu River pale, greenish grey, leuco-tonalites crop out. The hornblende-bearing tonalites, together with the darker varieties of biotite tonalite, display a coarse, poorly developed foliation which trends northeast or east-northeast. The composition of these rock types is identical to those occurring in the Skombeni area.

(c) Mkhondo Valley

A poorly exposed area, 40 square km. in extent, is underlain by gabbro, quartz gabbro and quartz diorite with minor amounts of ultramafic rock. Ribs and small bosses of grey, homogeneous, biotite-microcline granite are found intrusive into these rock types.

Hornblendite, composed of smoothly interlocking subhedral grains of hornblende pleochroic in shades of brownish green, is found in association with gabbroic rocks. Some diopside is present also in the hornblendites.

The gabbro is composed of an inequigranular mosaic of plagioclase (An_{54}), hornblende and diopsidic augite. Hypersthene may be present in which case the gabbro has noritic affinities. Both hypersthene and diopside are associated with hornblende and all three minerals may display an imperfect sub-parallel alignment of their longer axes. With an increasing quartz content the pyroxenes are progressively altered until only residual cores are preserved in amphibole laths, which themselves display marginal alteration to chlorite. The turbidity of the plagioclase grains increases with the appearance of quartz, the composition of the plagioclase changing to An_{40} in the varieties which contain most quartz.

C. THE HOMOGENEOUS HOOD GRANITE

This granite, with a Rb/Sr age of 3070 ± 60 m.y. (Allsopp et al., 1962), is extensively developed along the eastern side, and continues into the Transvaal around the southern end, of the Swaziland Sequence. The granite builds a gently rolling peneplaned plateau standing at elevations between 1220 and 1525 metres above sea-level. Scattered boulder-strewn tors and curved granite pavements diversify the plateau. A similar plateau extending from the southern Swaziland border to the Usutu River is also built by this granite.

The granite is typically a massive, grey, medium- to coarse-grained rock composed of quartz, microcline and plagioclase with subordinate biotite or, more rarely, hornblende. Accessory minerals include apatite, sphene, zircon, allanite and epidote. The granite is cut by a complex stockwork of pegmatites, usually of small size, composed of quartz and feldspar. Certain of the pegmatites, particularly those located within a belt, 5 km wide, extending southeastwards from the Transvaal border through Mbabane, carry economic minerals of which cassiterite is the most important. Other rare minerals found in the pegmatites of this belt include yttrotantalite, beryl, monazite, columbite, and euxenite.

In some of the more deeply incised valleys it can be seen that the granite passes downwards into the Ancient Gneiss Complex. Where the present topography is steep the change takes place over relatively short distances. However, north and west of Mankaiana the erosion surface of the plateau is close to the contact, with the result that a complex migmatite zone is found. The contact zone is marked by the appearance of narrow dykes and thin sheets of grey granite or of granite with pegmatitic portions. The numbers of these dykes and sheets increase upwards so that only fragments of gneiss remain. Higher still the zone is essentially granite with wisps and xenoliths of gneiss, which are usually deformed. Some metasomatism has been observed in the gneisses, particularly southeast of Mbabane, where porphyroblasts of plagioclase and, nearer the granite, microcline appear in the gneisses. With the gradual increase in the abundance of these porphyroblasts the gneiss texture is destroyed and there is a gradation into mesocratic and, finally, leucocratic grey granite.

Along most of its contacts with the Swaziland and Pongola Sequences, the granite displays its normal characters but around the southern end of the Swaziland Sequence the granite is foliated and there is a gradation from the foliated granite into metasomatized country rocks consisting of quartz-sericite gneisses interlayered with more mafic gneisses belonging to the Swaziland Sequence. The foliated granitic rocks are adamellites. About 2 km south of the Mbabane-Johannesburg road the more typical grey granite truncates the foliated adamellite, and is in direct contact with rocks of the Swaziland Sequence, which are metamorphosed to the pyroxene hornfels facies in a narrow contact aureole.

North of Pigg's Peak three small, moderately porphyritic, granite bodies are located along the contact between the Swaziland Sequence and the normal homogeneous granite. Exposures are poor so that no contacts between the porphyritic granites and the homogeneous granite can be observed, but the former are transgressive to textures in the latter. These porphyritic granites have been regarded as marking a final stage of the emplacement of the homogeneous granite but the possibility cannot be excluded, in the light of the findings of van Eeden and Marshall (1965) and Viljoen and Viljoen (1969a) that these three bodies may be later plutons similar to those occurring in the adjacent areas of the Transvaal.

TABLE II

MINERALOGICAL DATA : HOMOGENEOUS HOOD GRANITES AND ADAMELLITES, AND GRANITE PLUTONS

	Homogeneous Hood Granites	Granite Plutons
Microcline	2V = 80° Nm = 1.523 Triclinicity value 0.96 Perthitic	2V = 80° Triclinicity value 0.95 Perthitic
Plagioclase	An_{26} to An_{32} 2V = 82° to 87° (-) Nm = 1.548 Carlsbad and albite twins In pegmatites An_6 to An_{15} 2V = 80° to 85° (+)	Distinctly zoned in older pluton, An_{18} to An_{26} Younger plutons An_{12} to An_{19} Nm = 1.540 Clear albite rims An_8 around microcline in older pluton
Biotite	Pleochroism X = straw yellow, Y = Z = brown or greenish brown Nm = 1.632 to 1.640 Chloritized	Pleochroism X = yellow-brown, Y = Z = brown or greenish brown
Hornblende	Pleochroism X = yellow green Y = bluish green, Z = green Nm = 1.685, 2V = 80° $Z \wedge c$ = 25°	Pleochroism X = yellow green, Y = green, Z = deeper green Nm = 1.671, 2V = 80°
Chlorite	Pleochroism X = Y = pale green Z = olive green, Nm = 1.620	

The Mozaan Group is intruded by the homogeneous granite. Apophyses of granite occur in quartz-sericite schists, particularly north of Mahamba. Xenoliths of quartzite are found south of Hlatikulu, where banded gneisses have been located on the flank of a large quartzite xenolith. Small bosses of leucogranite approximately 0.6 sq. km in extent intrude the gneisses. Further information is required from this area in order to determine the age relations of these gneisses.

Contact metamorphism of the Swaziland and Pongola Sequences by the homogeneous granite is limited to a narrow aureole, rarely more than 200 metres wide. The grade of metamorphism reaches the pyroxene hornfels facies.

D. THE GRANITE PLUTONS

Seven coarse-grained, usually porphyritic, granite plutons have been identified in Swaziland and a further three in the vicinity of the Swaziland Sequence have been recognized in the Transvaal. Two ages of pluton emplacement have been found in Swaziland (Hunter, 1968) and a two-fold grouping has been proposed by Viljoen and Viljoen (1969) in the Transvaal.

That there are at least two ages of pluton emplacement in Swaziland is based on the field evidence which shows that the Mhlosheni and Mooihoek plutons intrude the older pluton found to the east of Mhlosheni. In the Transvaal, Viljoen and Viljoen (1969a) have based their separation of two ages of pluton emplacement on age measurements, which are regarded by Oosthuyzen (1969) as "very provisional". There is no evidence to indicate the age of the Mbabane, Sinceni, Sicunusa and Ngwempisi group of plutons relative to the Mooihoek and Mhlosheni plutons.

The plutons are distinctive by virtue of their topographic expression, lithology, mode of emplacement and limited metamorphic effects. The plutons give rise to rugged, generally bush-covered country, with prominent, large, rectangular tors (i.e. castle koppies). All the plutons are sharply transgressive and abruptly truncate structures in older rocks, often without pronounced disturbance.

(a) Older Pluton

A very coarsely porphyritic granite occupies an area of 350 sq. km in southern Swaziland. Porphyritic microcline crystals have long axes of between 25 and 50 mm. In some outcrops the insets are so closely packed as to produce a rock of pegmatitic aspect. Occasionally the microcline insets are mantled by narrow, more opaque, cream-coloured rims of plagioclase (An_{18}). More medium-grained, less porphyritic granite crops out in the northern portion of the pluton, where it builds higher ground. This granite has the appearance of being a roof or marginal phase.

The granite is composed of quartz, microcline, plagioclase and biotite. The microcline is coarsely perthitic and usually includes fragments of plagioclase, having a turbid core and a clear albite rim, and quartz. Biotite occurs as large ragged laths usually wholly or partially chloritized. Hornblende is also present particularly in the granite near its contact with the Insuzi Group. No hornblende has been observed in the more medium-grained granite. Pegmatites are rare to absent. Accessory minerals include sphene, apatite, zircon and allanite.

(b) Younger Plutons

Of the six younger plutons four are coarse-grained and porphyritic, while two are coarse-grained (i.e. Mhlosheni and Mooihoek). The granites building the plutons are homogeneous, the porphyritic granites having a grey or pink colour. The granites building the Mhlosheni and Mooihoek plutons are grey-green in colour, due apparently to a deficiency of mafic minerals. Biotite generally tends to occur in clusters in the porphyritic granites. No pegmatites are known.

The contacts of the plutons are often obscured by abundant talus but where a contact has been located, it is sharp and the granites retain their coarse-grained texture. No alignment of the microcline insets can be seen near the contacts. A distinctive feature of the Mbabane, Ngwempisi and Sicunusa plutons is the presence of medium-grained, biotite-rich inclusions which often have a disc-like shape. These inclusions are randomly oriented and large microcline porphyroblasts may grown in them.

The porphyritic granites are composed of quartz, microcline, plagioclase and biotite with accessory allanite, zircon, apatite and sphene. The Mhlosheni and Mooihoek plutons are composed of quartz, microcline, and plagioclase with subordinate, chloritized biotite.

E. CHEMISTRY OF THE GRANITIC ROCKS

In Tables III and IV the average compositions of the Swaziland granitic rocks are given and compared to those determined by Viljoen and Viljoen (1969b).

Attention has already been drawn to the chemical changes observed in the granites accompanying decreasing age [Hunter (1957, 1965, 1968) and Viljoen and Viljoen (1969b)] and a full discussion will not, therefore, be repeated.

A comparison of the average analyses shows that chemically the tonalitic gneisses of Swaziland and the diapiric domes in the Transvaal are similar, there being a slight increase in total alkalies (although the proportions remain constant) and a decrease in calcium in the diapiric domes. The hornblende tonalitic gneiss and the Kaap Valley Granite are also chemically similar, although their geological settings differ.

TABLE III

AVERAGE ANALYSES TONALITE GNEISS,
GRANODIORITE SUITE AND HOMOGENEOUS GRANITE

	I				II			III			
	A	B	C	D	A	B	C	A	B	C	D
SiO_2	71.16	65.44	70.96	64.84	56.22	67.67	71.26	72.53	73.13	72.21	75.29
TiO_2	0.34	0.42	0.18	0.49	0.77	0.49	0.37	0.25	0.20	0.25	0.12
Al_2O_3	14.84	15.23	14.93	15.44	19.73	15.92	14.46	13.84	13.81	14.39	12.20
Fe_2O_3	0.77	0.98	0.79	1.80	2.02	1.09	1.39	0.95	0.75	0.66	1.23
FeO	1.52	3.33	1.04	2.44	3.98	2.20	0.80	1.34	1.27	1.33	1.16
MnO	0.02	0.08	0.05	0.04	0.10	0.05	0.04	0.10	0.12	0.03	0.02
MgO	0.95	3.20	0.78	2.60	2.51	1.29	0.84	0.52	0.55	0.60	0.53
CaO	3.18	4.69	2.32	4.25	5.40	3.58	1.80	1.38	1.07	1.58	1.35
Na_2O	4.82	4.38	5.38	4.93	5.26	4.58	4.65	3.63	3.28	4.37	3.65
K_2O	1.65	1.57	1.92	1.53	2.76	2.10	3.55	4.81	5.35	3.57	3.44
H_2O+	0.75	0.96	0.56	0.90	1.09	0.98	0.67	0.63	0.63	0.58	0.53
H_2O-	0.07	0.09	0.13	0.20	0.09	0.50	0.08	0.08	0.08	0.16	0.13
P_2O_5	0.12	0.13	0.06	0.18	0.33	0.17	0.13	0.25	0.06	0.10	0.15
CO_2	-	-	-	-	-	-	-	-	-	0.43	-
No. of Analyses	6	2	3	4	2	6	1	7	5	3	3

I : TONALITIC GNEISSES AND DIAPIRS

A : Tonalitic Gneiss, Swaziland. Average of analyses M338, H440, H1138, H1147, H1241, (Hunter, 1968) and Analysis 42 (Visser, 1964).

B : Hornblende Tonalite Gneiss, Swaziland. Average of analysis H430 (Hunter, 1968) and analysis 51 (Visser, 1964).

C : Tonalitic Diapirs, Transvaal. Na_2O and K_2O average based on 11 determinations (Viljoen and Viljoen, 1969b, p. 193).

D : Kaap Valley Granite (hornblende tonalite). Na_2O and K_2O average based on 7 determinations (Viljoen and Viljoen, 1969b, p. 192).

II : GRANODIORITE SUITE

A : Quartz diorite, Swaziland. Average of analyses H642 and H1124 (Hunter, 1968).

B : Leucocratic tonalite (trondhjemitic) Swaziland. Average of analyses H608, H1047, H1145, H1214 and H1088 (Hunter, 1968).

C : Mliba granodiorite, Swaziland. Analysis H1279 (Hunter, 1968).

III : HOMOGENEOUS GRANITE AND NELSPRUIT GNEISS

A : Homogeneous Granite, Swaziland. Average of analyses H516A, H1272, H334, H540, H506, H857 and H892 (Hunter, 1968).

B : Homogeneous Granite, Swaziland. Average of analyses H334, H540, H506, H857 and H892. These analyses are of the most completely homogenized granites, whereas the average given in IIIA above includes granites within which gneiss relicts are present.

C : Nelspruit Migmatites and Gneiss, Transvaal. Na_2O and K_2O based on 10 determinations (Viljoen and Viljoen, 1969b, p. 195).

D : Homogeneous Granite Migmatites, Swaziland. Average of analyses H1174, Grout (1935) and analysis 43 (Visser, 1964).

TABLE IV

AVERAGE ANALYSES GRANITE PLUTONS

	A	B	C	D	E
SiO_2	69.52	71.88	70.42	69.58	71.50
TiO_2	0.67	0.37	0.35	0.35	0.19
Al_2O_3	13.52	13.58	14.79	14.48	14.22
Fe_2O_3	1.90	0.70	0.88	1.02	1.32
FeO	2.10	2.08	1.38	1.42	0.99
MnO	0.42	0.05	0.05	0.04	0.05
MgO	0.84	0.56	0.91	1.10	1.11
CaO	2.18	2.32	1.82	2.25	1.51
Na_2O	2.94	3.16	4.65	5.08	3.43
K_2O	4.78	5.11	3.61	3.40	5.15
H_2O+	1.09	0.50	0.70	0.97	0.40
H_2O-	0.03	0.10	0.13	0.21	0.05
P_2O_5	0.17	0.09	0.14	0.19	0.08
No. of Analyses	1	2	3	2	1

A : Older pluton, Swaziland (H872) (Hunter, 1968).

B : Younger plutons, Swaziland. Average of analyses H451 and H532, (Hunter, 1968), Na_2O and K_2O average includes SG5 (Viljoen and Viljoen, 1969b).

C : Older plutons, Transvaal. (Viljoen and Viljoen, 1969b, p. 197).

D : Average Dalmein (Older Pluton). (Viljoen and Viljoen, 1969b, p. 197).

E : Younger pluton (Mpageni), analysis GS4 (Visser and Verwoerd, 1960), Na_2O and K_2O averages based in addition on Viljoen and Viljoen (1969b), p. 202, and Fourie (1969) p. 224.

The leuco-tonalite of the Granodiorite Suite has been included by Viljoen and Viljoen (1969a) in their Ancient Tonalitic Gneisses. While there are chemical similarities, the field evidence cannot be ignored. The Granodiorite Suite rocks are coarse-grained and intrude the medium-grained, foliated tonalite gneisses of the Ancient Gneiss Complex. The remarkable uniformity of the analyses of the tonalitic gneisses from Swaziland is not reflected in the Granodiorite Suite, which in general has, as far as the acid members are concerned, more potassium than the tonalitic gneisses. On purely chemical grounds the Mliba granodiorite shows a close similarity to the older plutons of the Transvaal (Table IV, C).

The average analysis of three migmatites associated with the homogeneous granite bears out the fact that the migmatites are in general richer in sodium than the homogeneous granite. The high silica value for the Swaziland migmatites is due to the fact that two of the analyses used in the average contain abnormally high quantities of silica, resulting from the migmatization of siliceous gneisses.

Although one analysis is not sufficient it does indicate that the Swaziland Older Pluton may be dissimilar to the Dalmein and Salisbury Kop plutons by virtue of its $K_2O:Na_2O$ ratio. Whereas Viljoen and Viljoen (1969a) report only scattered K-feldspar phenocrysts in the Dalmein and Salisbury Kop granites, microcline phenocrysts are common and often abundant in the Swaziland Older Pluton. As has been pointed out the Mliba granodiorite bears a chemical resemblance to the Salisbury Kop granite. Again one analysis is not enough to make direct comparisons, but the general petrological similarity suggests that this pluton, at present correlated with the Granodiorite Suite, could possibly be equated with the Salisbury Kop granite.

The contrast in chemistry between the homogeneous granites and the granite plutons is of interest. In Table III, column IIIB, the average of five homogeneous granite analyses is given (excluding the analyses H516A which is located in the albitized tin belt and H1272 which is close to the migmatitic zone). This average is similar to that contained in Table IV, column B which is an average analysis of the younger granite plutons. The main point of difference is the lower content of mafic components (TiO_2, FeO and CaO) in the homogeneous granite. In comparison with the Older Pluton, the homogeneous granite contains more SiO_2, Al_2O_3 and K_2O and fewer mafic components (TiO_2, Fe_2O_3, FeO, MnO, MgO and CaO). These contrasts are not apparent, however, when the homogeneous granite analyses are compared to the Transvaal plutons.

ORIGIN OF THE GRANITIC ROCKS

The origin of the tonalitic gneisses in the Ancient Gneiss Complex has been briefly summarized in this paper, and a fuller treatment appears elsewhere (Hunter, 1970). The origin proposed here differs from that offered by Viljoen and Viljoen (1969b) who visualize a tonalite magma, developed as a complementary response to the mafic and ultramafic lavas of the Onverwacht Group, giving rise to the diapiric domes. The relationships observed in the Transvaal-Swaziland area are not unlike those found in many basements, for example the Karelides where the basement rocks are both older and younger than their cover rocks. This apparent contradiction results from the regeneration of the basement in response to a younger thermal and deformational event. Arguments against the derivation of the tonalitic gneisses in Swaziland from the intrusion of magma have been given. The overall similarities in petrology and chemistry between the Swaziland tonalitic gneisses and the diapiric tonalites are not in dispute, nor is the fact that the latter are intrusive into the Swaziland Sequence. That the intrusive diapirs result from the reactivation of the basement tonalitic gneisses is not unreasonable and is in conformity with phenomena observed elsewhere. The fact that the diapiric tonalites are somewhat richer in alkalies than the widespread tonalitic gneisses provides some support for the view that the diapiric domes could represent mobilized, or partially mobilized, tonalitic gneisses.

The Granodiorite Suite has been placed in the Ancient Tonalitic Gneisses by Viljoen and Viljoen (1969a). These authors regard the mafic and ultramafic rocks in the Granodiorite Suite as xenoliths of Onverwacht material in an intrusive tonalitic magma. There is agreement that the Granodiorite Suite was derived from a magma. The intrusive nature of the tonalitic and quartz dioritic members of the Granodiorite Suite can be demonstrated in good exposures, which also reveal that the Ancient Gneiss Complex had suffered granitization prior to intrusion of the Granodiorite Suite. Although chemical similarities do exist, there is an important difference. The tonalitic gneisses of the Ancient Gneiss Complex are remarkably uniform in their chemistry (with the exception of the hornblende tonalite gneisses which are confined to a discrete area forming a second uniform group). The tonalitic members of the Granodiorite Suite have trondhjemitic affinities, a feature not reflected in the tonalitic diapirs or gneisses.

The following characteristics of the Granodiorite Suite are significant :

(a) Plagioclase displays a continuous series with zoned plagioclase having more calcic cores.

(b) There is a sympathetic increase in microcline and silica content (with the exception of the anomalous quartz diorite [H642]).

(c) There is a gradual increase in the ratio FeO:MgO and (Na_2O + K_2O):CaO with increasing silica content.

The ultramafic fragments in the tonalitic and quartz dioritic rocks are usually coarse-grained and no similar rock types have been found beyond the confines of the Granodiorite Suite.

If the Kaap Valley Granite is regarded as a tonalitic diapir having a more basic nature than the other diapirs as a result of contamination, the question must be asked why the Granodiorite Suite has been basified even further if it too represents tonalitic magma contaminated by Onverwacht material. This is all the more surprising if it is remembered that the greater proportion of the Ancient Gneiss terrain, into which the Granodiorite Suite is intruded, is of tonalitic bulk composition. Consequently, if basification of the original magma by contamination took place, it must have been caused not by the rocks of predominantly intermediate composition now seen on outcrop but by other material.

In the quartz dioritic rocks cores of pyroxene are preserved in some amphibolitic laths, which implies that incorporation of more acid material by the original magma has caused this reaction. In other words the original magma became more siliceous.

The Granodiorite Suite is considered to stand as a separate entity, its origin lying in a magma generated at depth and modified as a result of a process akin to zone melting for simple differentiation could not be expected to give the high proportion of acidic rocks. If it is accepted that the early Precambrian crust was thin, the depression of the crust caused by the great thickness of Swaziland Sequence rocks deposited on this relatively unstable base would have been sufficient to depress the lower portion of the crust into a zone of melting with upper mantle material. Hamilton (1964) considers that melting of basaltic rocks at pressures appropriate to the lower crust or upper mantle could produce high alumina-basalts, andesites and dacites. The temperature range of melting of basaltic rocks at the pressures expected is broad. Plagioclase is, at these temperatures, a much lower temperature mineral than pyroxene or amphibole. Hence melting would produce feldspathic magmas which would become enriched in calcic feldspar and mafic minerals as temperatures increased and melting continued. If some crustal material is also involved in the melting and the magma so produced is modified as a result of contamination by zone melting, a rock series could result similar to that represented by the Granodiorite Suite. It is envisaged that the Suite is the response to the weight of the superincumbent Swaziland Sequence depressing the crust into the zone of magma generation. Modification of the original magma caused by zone melting followed as the newly generated magma passed upwards through the crust.

The next major granitic event is marked by the homogeneous granite. The characteristics of this granite are :

(a) it does not belong to a compositional plutonic series grading from basic into acid types;

(b) contacts may be gradational, migmatitic or intrusive;

(c) the most uniform granites contain more potassium than eutectoid granites;

(d) strongly zoned plagioclase is rare.

The analyses of the homogeneous granite are remarkably uniform. Only when analyses have been made on samples collected near the contacts in migmatitic zones have the analyses shown any change mainly by decreases in the silica content and in the $K_2O:Na_2O$ ratio. In Table III, columns IIIA and B demonstrate this fact.

The contacts of the homogeneous granite have been described. The potash-rich late fraction abruptly truncates the foliated earlier adamellitic portion. Dykes and tongues of homogeneous granite cut country rocks with only limited metasomatic effects being observed in the rocks of the Swaziland and Pongola Sequences. The evidence, both field and petrological, supports the view that the homogeneous granites crystallized, at least in part, from a melt.

Experimental studies (Winkler, 1965) have shown that in assemblages consisting principally of feldspars, quartz and ferromagnesian minerals, most of the quartz, orthoclase and albite enter the melt near the minimum melting temperature and that the remaining constituents do not enter the melt until higher temperatures are reached. It would be possible, therefore, to derive an anatectic melt of a composition appropriate to the homogeneous granite by this process. Fluctuations of temperatures within the zone of anatexis would account for the subtle variations in chemical composition. However, anatexis of the Ancient Gneiss Complex would seem to provide an inadequate volume of potash-rich melt necessary to give rise to the extensive homogeneous granites. Neither is there a source of potassium-rich rocks in the Swaziland Sequence. It would appear, therefore, that some thermal event in the mantle provided the necessary volume of potassium.

The process of anatexis is often regarded as a result of the down-buckling of a eugeosynclinal pile followed by the intrusion of magma, generated in this way, into the axial zone of the geosyncline. The homogeneous granite is not related to an axial zone and intrudes cratonic sediments of the Pongola Sequence. There is no evidence that the homogeneous granite resulted from anatectic melting of downwarped crustal rocks. Rather it seems that there was a fairly passive upward movement of potassium-rich material which collected at higher levels to crystallize as an increasingly more homogeneous granite as it became further dissociated from the underlying Ancient Gneiss Complex. Although the gneisses become porphyroblastic, banded, folded and migmatitic as the homogeneous granite is approached, it is considered that most of the apparent deformation results from plastic movement due to the elevated temperature which prevailed at the base of the homogeneous granite sheets.

Where the homogeneous granite is intrusive into the Swaziland and Pongola Sequences they develop a narrow, thermal metamorphic aureole reflecting a steep geothermal gradient. This condition suggests that the homogeneous granite was formed at relatively high crustal levels but there is no evidence available to indicate what form the roof of the homogeneous granite had or what materials constituted the roof.

The last event in the Swaziland Precambrian was the emplacement of transgressive plutons. Two ages can be demonstrated in Swaziland, for the Mhlosheni pluton intrudes the Older Pluton underlying the country to the east of Mhlosheni. In the Transvaal plutons of two ages are also recognized with the older group having a granodioritic composition. Inadequate chemical data are available from Swaziland to indicate whether this condition also pertains there but the one analysis of the older pluton clearly shows a high $K_2O:Na_2O$ ratio.

The random distribution of the plutons and lack of fabric within them provide no help in determining either their shape or mode of emplacement. That a considerable period of time elapsed between the younger plutons and the homogeneous granite is indicated by the facts that (i) the gabbroic, Usushwana Complex was intruded during this time gap and (ii) that age measurements indicate a difference of some 400 m.y. between the two granite events.

TECTONIC SETTING AND CLASSIFICATION

It has long been recognized that granitic rocks have different tectonic styles with which are associated petrological and chemical distinctions. These differences have provided the basis of various schemes of geotectonic classification. In Scandinavia, three groups are recognized which are characteristic of emplacement at different times during the evolution of an orogenic belt. It is further believed that successive orogenies, if completely developed, will exhibit a repetition of the different groups.

Eskola (1932) proposed to divide granitic rocks in Finland into three magmatectonic types, namely synkinematic, late-kinematic and post-kinematic. Wahl (1936) stressed a similar relationship between the style of a granite and its setting in an orogenic cycle. Both authors recognized that the gneissic plutonic rocks formed at an early stage of the orogenesis are predominantly granodioritic in composition. The second group (late-kinematic) are microcline granites forming migmatites with the synkinematic intrusives and their sedimentary or volcanic country rocks. The post-kinematic rocks are, according to Eskola (1932), best represented by the rapakivi granites. Marmo (1962) has drawn attention to the fact that orthoclase is more typical of this group than of any of the other Precambrian granites.

Read (1957) erected the Granite Series in which he attempted to relate "the nature and form of different types of granitic bodies with their place in the fold-belt and the time of their final solidification". Read envisaged four granitic types ranging from deep autochthonous granitization granites through parautochthonous granites and intrusive magmatic granites to high-level plutons.

Buddington (1959) reviewing granite emplacement in North America found that Read's Granite Series needed revision particularly in regard to the Tertiary stocks and batholiths of the United States. Buddington preferred to relate granite emplacement to three crustal zones, namely the cata-, meso- and epizones.

Inherent in the geotectonic classification of acid plutonic rocks is the principle that the development of granitic rocks is related to orogeny and metamorphism in a mobile belt. Simonen (1960) has summarized this point of view in the following words - "The abundance of acid plutonic rocks in orogenic zones suggests that conditions favourable to the development of acid magmas prevail in deep parts of mobile orogenic belts, where great masses of sial crust have been depressed into a zone of anatexis".

Zagt (1969) has summarized the characteristics of the Hercynian and Alpine orogenic belts, and has compared them with other fold belts. The Hercynian orogeny is characterized by low pressure, high temperature metamorphism, high geothermal gradients, abundant and extensive granitic rocks, few initial magmatic rocks and wide extent. The Alpine fold-belt exhibits high pressure, low temperature metamorphism, low geothermal gradients, narrow width of the belt, a scarcity of granitic rocks and abundant ophiolites. The Caledonian and Grenville belts have characters intermediate between the Hercynian and Alpine types. Both the Svecofennian-Karelian and Sveconorwegian (or Dalslandian) orogenies are regarded by Zagt to be of Hercynian type. Zagt (1969) finds that the incidence of Hercynian-type orogenies through time suggests a cyclic repetition at intervals of approximately 700 m.y., and he extrapolates this periodicity to forecast that a Hercynian-type orogeny would be expected at 3,200 m.y. or approximately coincident with the age of the Swaziland mobile belt. Zagt finds that a cyclicity for Alpine-type orogeny is less well established, and attributes the apparent scarcity, in part, to the fact that their characteristics render their chances of survival small, because of deep erosion and/or transformation beyond recognition as a result of involvement in a later Hercynian-type orogeny.

Zagt has attempted to construct a model to explain the features observed in Alpine-type fold belts. He considers that, if high heat flow occurs on rising convection currents as appears to be the case on mid-oceanic ridges, it is reasonable to suppose that lower than normal heat flow can be expected at sites of descending convection currents, where crustal material is dragged down, and hence would provide appropriate conditions for high pressure, low temperature metamorphism. This model does not account for the features observed in Hercynian type fold-belts, which cannot be related to the sites of rising convection currents because these are apparently related to mid-oceanic ridges which are narrow, linear features. Zagt postulates the possibility that parts of the crust may have drifted onto mantle material with high heat flow, resulting in the slow heating of the crust leading to metamorphism at a relatively high temperature and the melting of crustal material to give granitic magmas. Zagt considers that "these processes may produce doming and intrusion, and perhaps small convection cells in the upper mantle or lower crust, leading to deformation of rocks, without involving large-scale shortening of the crust". In this model folding and deformation are regarded as secondary, initiated by the metamorphic and magmatic activity. Zagt further visualizes that "the unequal heat distribution ..... would establish a number of convection cells, resulting in the breaking up of continents, and the drift of the continental crust onto lower heat flow mantle, ending the Hercyno-type orogeny and starting the Alpinotype one".

Zagt's proposals are similar to the concept proposed by Sutton (1963) of chelogenic cycles with which model he attempts to reconcile the coincidence of Runcon's (1962) calculated changes in the convection system of the mantle with the peaks of plutonic and metamorphic activity determined by Gastil (1966) from a world-wide study of radiometric age determinations. Sutton has proposed four chelogenic cycles which he has named Kola (+ 2900 m.y.), Shamvaian (2750 m.y.), Svecofennid (1900 m.y.) and Grenville (1200-1000 m.y.). Sutton considers that each cycle was initiated at about the times given above and that each endured for 750 to 1250 m.y. A chelogenic cycle "consists of a sequence of events which leads to the displacement and disruption of the continents as they existed at the start of the cycle and later re-grouping of these disrupted masses of continental crust". A cycle is believed to start with sedimentation preceeding a return of mountain building, which at an early stage of the cycle forms a network over the continents, which at this stage are grouped in clusters. Orogeny becomes more restricted, as the cycle develops, in the central areas of continents and large non-orogenic regions are distinguished in each continent surrounded by "a peripheral region where orogeny continues in parts of the original network of mountain chains or in their close proximity".

These proposals are worthy of further consideration particularly within the Rhodesian and Kaapvaal cratons where many of the best-preserved rocks, plutonic, volcanic and sedimentary, of great antiquity are found. The tectonic setting of the granitic rocks within these cratons and their comparison with similar rocks developed during younger events provide one of the means whereby the concepts summarized above can be tested.

Attempts have been made to accommodate the Swaziland Sequence of granitic rocks into the geotectonic groupings proposed for younger orogens (Hunter, 1965 and 1968), but it became apparent that important differences existed which could not be reconciled with the classic models. Roering (1967) and Engel (1968) contended that the sequence of granites in the earliest Pre-cambrian was developed under significantly different conditions from those in younger cycles.

The tonalitic gneisses of the Ancient Gneiss Complex are consistent in their character with the autochthonous granitization granites of Read and the tonalitic diapirs could represent the earlier stages in the development of parautochthonous granites. The Granodiorite Suite is intrusive into the Ancient Gneiss Complex as semi-concordant bodies, the foliation being parallel to the long axis of the individual bodies. The syntectonic nature of this granite is therefore indicated, and reasons have been advanced to suggest that the Suite had a magmatic origin in the upper mantle and lower crust, suggesting a parallel with the syn-kinematic intrusives of the Svecofennian orogen.

The Homogeneous Hood Granite was classed as late-orogenic (Hunter, 1965). Its petrological characters, lack of differentiation products, migmatitic aureole, and chemistry are typical of the late-kinematic granites of Scandinavia (Simonen, 1948 and 1960), but the Homogeneous Granites are not arranged in linear belts along a geosynclinal axis and intrude the non-eugeosynclinal rocks of the Pongola Sequence. Late-kinematic granites in geosynclinal environments are believed to have been derived from the anatexis of the down-buckled base of the geosynclinal pile. There is no evidence that the Homogeneous Hood Granite originated in this way for reasons already given.

The granite plutons in Swaziland and the Transvaal bear on superficial examination a resemblance to the post-kinematic plutons. Read (1957) writes "The final term of the granite series is represented by the high-level plutons, intrusive into the non-plutonic regions late in the history of the orogen concerned ..... The plutons are the domain of the Granite-tektonik of the Cloos school and, as their emplacement produced considerable folding and distortion in the country rock surrounding them, they came in as almost dead bodies".

The granite plutons in Swaziland are remarkable for the general lack of strong deformation related to their emplacement in spite of the sharply transgressive contacts truncating structures in the older rocks. Unlike the high-level plutons of Read's Granite Series, there is a lack of fabric in the granites building the plutons, which are randomly oriented and distributed through the granitic terrain. Marmo (1962) has drawn attention to the fact that the post-kinematic plutons in Scandinavia are orthoclase-bearing and may contain mantled feldspars. Harpum (1961) reports that the apparently Proterozoic, post-orogenic granitic rocks of Tanzania carry perthitic potash feldspar or orthoclase inverting to microcline with a very diffuse cross-hatch twinning. They frequently exhibit Rapakivi affinities with mantled feldspars. Harpum notes that these granites occur in association with orogenic phyllites but, "in the geological cycles in which they are found, there does not appear to be any development of either synorogenic or late-orogenic granitic material". Harpum considers that his post-orogenic granites have developed from various porphyroblastic migmatites by metablastesis. In contrast the Swaziland granite plutons are sharply defined bodies with evidence of metasomatic activity indicated by the growth of microcline in the disc-like mafic inclusions present in certain of the plutons. The potash feldspar is microcline : triclinicity values of this feldspar in the pluton granites are consistently greater than 0.88 and average 0.95.

Late-orogenic granites, particularly in Alpine- and Caledonian-type fold belts, are typically linear and are located in the eugeosynclinal environment. However, Hamilton and Myers (1967) have drawn attention to the fact that the granitic batholiths in North America are not wholly confined to this location. The Homogeneous Hood Granites are sheet-like in form, have a wide distribution, extending beyond the bounds of the Barberton Mountain Land, and are associated with a mobile belt displaying low temperature and relatively low pressure metamorphism, from which it may be concluded that neither Hercynian nor the Alpine orogenic models satisfy the observed facts. The batholiths of the western United States, regarded by Zagt (1969) as being within an Alpinotype fold belt, are sheet-like in form (Hamilton and Myers, 1967), a feature which finds a parallel in the Homogeneous Hood Granites.

The Homogeneous Hood Granite was emplaced in more than one heave. At the southern termination of the Swaziland Sequence in the Usushwana Valley, siliceous schists of the Onverwacht Group have suffered metasomatism with the result that there is a gradual transition from foliated adamellite into metasomatized gneiss. The foliated adamellites are truncated by the later potash-rich phase which caused thermal metamorphism in the immediate contact. In country rocks of the appropriate composition, garnet and diopside are found. Two generations of tremolite can be identified in the more basic country rocks, the first as oriented flakes and the second, found near the granite contact, being randomly arranged. The fact that the contact metamorphic minerals are not preferentially aligned indicates that the Homogeneous Granite was emplaced after the waning of the stress field. The deformational style of the Swaziland Sequence is relevant to the tectonic setting of the Homogeneous Granites. The Swaziland Sequence has been deformed into tight synclinal structures separated from each other by high angle faults forming a deep wedge within the sea of granitic rocks. Macgregor (1951) noted the difference in the specific gravity of the supracrustal rocks of the Rhodesian schist belts and of the enveloping granites. He proposed that the structures in the schist belts resulted from the sinking of the heavier supracrustal rocks into the lighter granitic rocks which rose around the schist belt. This mechanism would result in vertical stretching rather than crustal shortening. In the case of the Pongola Sequence consisting largely of rocks of a specific gravity close to that of granite gravitative sinking would be less pronounced and this is reflected in the deformational style found in these rocks, which are folded in more open synclinal and anticlinal structures.

The tectonic setting of the Homogeneous Granites is at variance with that found in either the Hercynian- or Alpine-type fold belts and is essentially non-orogenic. The view that the Granodiorite Suite is a first response to the depression of a thin crust and the upper mantle into a zone of melting a result of the sinking of the Swaziland Sequence is not invalidated by this concept. What is unacceptable is the classification of this Suite as a syn-kinematic intrusion in the strictest sense, although the end results bear close similarities to those found in an orogenic environment.

Of interest is the close chemical and petrological similarity between the apparently non-orogenic Homogeneous Granite and the late-kinematic granites. In the latter case, the source of the abundant potassium is thought to lie in the anatexis of geosynclinal sedimentary rocks but this explanation is inadequate for the Homogeneous Granites. More information is required as to the distribution of the Homogeneous Hood Granites in order to resolve the problems attendant upon their genesis and tectonic setting, in the light of their chemical and mineralogical similarity to granitic rocks originating as a response to orogenic as distinct from anorogenic conditions.

The use of the tectonic classification of granitic rocks applicable in fold belts of lesser antiquity than the earliest Precambrian is unsatisfactory, because it appears that first-formed acid plutonic rocks are unrelated to orogenesis. Modification of the concepts of Zagt and Sutton may be necessary, for it appears that there was a significant change in the style of the structural and thermal domains after the earliest Precambrian.

In an attempt to supply a provisional tectonic grouping for the earliest acid plutonic rocks, the following are proposed :

(i) Autochthonous Plutonic Rocks

Complexes of granitized (or more properly granodioritized) gneisses intimately associated with regionally metamorphosed rocks. Strongly foliated and associated with migmatites, the leucosome of which may be in part derived from the parent rock or in part have an arteritic origin.

(ii) Diapiric Domes

Rocks of the autochthonous plutonic group re-activated in response to the gravitative settling of later ultramafic and mafic rocks and associated sediments deposited in mobile belts.

(iii) Chelogenic or Shield-Forming Plutonic Rocks

Widespread, potassium-rich granites which form a hood zone over the gneiss basement, their distribution being unrelated to the original geometry of the schist belts which they envelop. In chemistry, mineralogy and association with mineral deposits are closely similar to late-kinematic granites of geosynclinal, orogenic belts. Emplacement of the chelogenic granites marks the welding together and stabilization of the early crust.

(iv) Anorogenic Plutons

Sharply cross-cutting plutons devoid of any internal fabric, randomly emplaced into the crust. Superficially similar to the end member of Read's Granite Series.

These four magmatectonic groups are apparently the non-orogenic equivalents of the syn-, late- and post-kinematic granites found in an orogenic environment, to which they have many similarities particularly in regard to chemistry and mineralogy. Although not represented in the earliest Precambrian in Swaziland, granitic rocks occur in another tectonic setting associated, in an anorogenic environment, with ring dyking and cauldron subsidence. Acid volcanic rocks are commonly related to these high-level intrusions which might be conveniently described as epizonal plutons.

The conclusion seems inescapable that the widespread Homogeneous Hood Granites and the Granite Plutons were developed in a setting, fundamentally different from that of younger orogenic belts. In the case of the Homogeneous Granite the "magma" from which it solidified apparently passed upwards, by virtue of its low specific gravity, through the crystalline basement, accumulating and spreading laterally at higher levels. The shape and downward extent of the plutons is not known, but granitic material must have remained available to continue the process of granite addition long after the solidification of the Homogeneous Hood Granite.

The preceeding classification is intended as a provisional attempt. Although the structural setting of granitic rocks in orogenic zones is well documented more information is required about the earliest granites. It is of importance to know whether there is a definite point in time when the emplacement of chelogenic granites ceased or whether such granites have been emplaced at times subsequent to the early Precambrian.

CONCLUSION

The recognition of a cyclic pattern of granitic types related to episodes of tectonic activity in mobile belts led to the concept of geotectonic classification. The syn-, late- and post-kinematic granites are found in the linear, orogenic zone which includes the geosyncline or geosynclines adjacent to a cratonic block or between two cratons. It is clear from the evidence in Swaziland that great volumes of granitic material were added to the crust which were not related to linear belts.

In Swaziland the earliest Precambrian saw the deposition of various sedimentary and volcanic rocks, probably in small depositories on the primeval crust. The environment in which these rocks were deposited is difficult to decipher because of the effects of subsequent metamorphism and granitization. Such evidence that is available suggests that the sedimentary rock accumulated in an unstable area as a result of rapid erosion and transport. No trace of the nature of the surface on which these rocks were deposited can be found. Regional metamorphism culminated in the production of gneisses having mineral assemblages appropriate to the cordierite-amphibolite facies which requires temperatures between 550° and 650°C, at pressures around 3000 bars. The metamorphites suffered contemporaneous deformation and granitization by ascending, superheated aqueous solutions migrating through the rocks while temperatures remained high.

It has not been satisfactorily proved whether this period of deposition, metamorphism and granitization pre-dates the Swaziland Sequence but circumstantial evidence indicates that this is a possibility.

The Swaziland Sequence consists of a great thickness of ultramafic "primitive" volcanics, mafic and acid volcanics, and sedimentary rocks. The Granodiorite Suite is nowhere in contact with this sequence but the Suite is found in bodies elongated sub-parallel to the regional trend of the Swaziland Sequence suggesting that it was emplaced synchronously with deformation of the Swaziland Sequence. In the Transvaal, diapiric domes of re-activated basement intrude the volcanic and sedimentary rocks of the Swaziland Sequence which, together with the thick succession of arenaceous and argillaceous rocks forming the Pongola Sequence, was subsequently intruded by the Homogeneous Hood Granite which collected in sheet-like bodies, its emplacement being unrelated to an orogenic belt.

The final granitic event in both Swaziland and the Transvaal was the emplacement at different times of plutons of coarse-grained, porphyritic granites.

Over the greater part of the Kaapvaal craton detailed information on the granitic rocks is lacking but in the Rhodesian craton acid plutonic rocks having different chemical compositions, tectonic settings and ages have been recognized (Macgregor, 1951; Bliss and Stidolph, 1969). The former defined four groups and the latter three groups of granitic rocks. Viljoen and Viljoen (1969c) have drawn attention to the similarities which exist between the Swaziland/Transvaal sequence and that in Rhodesia. Noticeable in published accounts, mainly by the Rhodesian Geological Survey, is the apparently less frequent development of highly potassic granites. The Raffingoro granite (analysis 60/359, Bulletin 49) is one of the exceptions, but no direct comparison can be made with Swaziland for it is described as a fine-grained, leucogranite with rare pegmatites. Similarly the published analyses of the cross-cutting, coarse-grained porphyritic granites such as the Matopos granite are more closely comparable to the Swaziland older pluton than with the younger plutons which have higher K_2O/Na_2O ratios. A further point of difference lies in the existence in Rhodesia of younger massive granites (Macgregor's group D) which are both sodic (Antelope Mine area, k value = 0.30) and potassic (Bikita area, k value = 0.51). It is uncertain where the granites should be accommodated but, as they are regarded as the youngest in their respective areas, it is possible that they represent a granitic event related to the circum-cratonic mobile belts, wherein Wiles (1961) has recognized in the Miami mica field both syn- and late-tectonic granites post-dating the Piriwiri "System".

However the sequence of granitic rocks in the central parts of the Rhodesian craton starts with gneissic tonalitic rocks, apparently diapiric in many areas, which were succeeded by medium-grained adamellites and finally by coarse-grained, often porphyritic and transgressive plutons. In addition stocks of gabbro, diorite and granite are found in many of the schist belts. The essential outlines of the pattern already established in the Kaapvaal craton are apparent in Rhodesia.

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APPENDICES

CHEMICAL ANALYSES OF GRANITIC AND ASSOCIATED ROCKS FROM SWAZILAND

The chemical analyses contained in the following appendices were used to calculate the mean values listed in Tables III and IV.

All the analyses with the prefix H before the sample number and the analyses listed in Appendix I as A and B were carried out by the Mineral Resources Division of the Overseas Geological Surveys, London (now incorporated in the Institute of Geological Sciences) to whom grateful acknowledgement is made.

Samples M338 and M492 were analysed by the Division of Chemical Services, Pretoria.

Samples Hamilton I and Hamilton II are quoted from : G.N.G. Hamilton, 1938, Further Notes on the Geology of the Country around Kubuta, Swaziland. Trans. geol. Soc. S. Afr., 41.

The sample labelled Grout is quoted from : F. Grout, 1935, The Composition of Some African Granitoid Rocks, J. Geol. 43, 294.

The locations of the samples are shown in Figure 2.

APPENDIX I

TONALITIC GNEISSES

A. CHEMICAL ANALYSES

	M338	H440	H1138	H1147	H1241	A	H430	B
SiO_2	71.90	70.99	70.56	70.85	73.14	69.53	68.42	62.46
TiO_2	0.50	0.30	0.29	0.39	0.06	0.42	0.32	0.53
Al_2O_3	13.75	15.46	14.35	15.32	15.05	15.13	15.45	14.92
Fe_2O_3	0.95	0.71	1.02	0.50	0.63	0.79	0.79	1.17
FeO	1.58	1.84	1.72	1.22	0.71	2.02	2.35	4.31
MnO	0.01	0.04	0.01	0.02	0.01	0.03	0.06	0.10
MgO	1.22	0.85	1.29	0.67	0.55	1.12	2.03	4.37
CaO	4.20	3.47	3.11	2.46	3.00	2.85	3.23	6.16
Na_2O	4.72	4.60	4.35	5.13	5.30	4.83	4.81	3.96
K_2O	0.92	1.24	1.98	2.83	1.10	1.85	1.88	1.26
H_2O+	0.43	0.63	1.08	0.73	0.45	1.17	0.80	1.12
H_2O-	0.09	0.08	0.05	0.05	0.06	0.10	0.07	0.11
P_2O_5	0.03	0.12	0.15	0.17	0.04	0.20	0.09	0.17
Total	100.30	100.33	99.96	100.34	100.10	100.04	100.30	100.64

B. NIGGLI VALUES

	M338	H440	H1138	H1147	H1241	A	H430	B
si	330	331	331	345	367	322	284	201
al	37.4	42.4	39.7	43.8	44.7	41.8	37.7	28.2
fm	17.8	15.7	19.2	11.7	9.7	16.1	23.6	35.6
c	21.2	17.5	15.5	11.7	16.3	14.4	14.4	21.3
alk	23.6	24.4	25.6	32.8	29.3	27.6	24.2	14.9
k	0.12	0.16	0.23	0.27	0.12	0.20	0.20	0.17
mg	0.47	0.45	0.47	0.42	0.44	0.49	0.53	0.59
c/fm	1.19	1.11	0.81	1.00	1.57	0.89	0.61	0.59

APPENDIX II

GRANODIORITE SUITE

A. CHEMICAL ANALYSES

	H1846	H642	H1124	H608	H1047	H1088	H1145	H1210	H1214	H1279
SiO_2	44.86	55.53	56.91	67.02	67.32	64.16	67.59	68.48	71.51	71.26
TiO_2	0.56	0.72	0.83	0.58	0.51	0.63	0.44	0.52	0.27	0.37
Al_2O_3	5.10	20.43	19.04	16.29	15.27	16.50	17.40	15.67	14.40	14.46
Fe_2O_3	5.53	1.97	2.08	1.04	1.31	1.50	0.82	0.82	1.07	1.39
FeO	5.37	3.58	4.39	2.53	2.49	3.01	1.21	2.42	1.57	0.80
MnO	0.27	0.11	0.09	0.05	0.05	0.08	0.01	0.04	0.04	0.04
MgO	22.63	2.32	2.70	1.44	1.79	1.71	1.01	1.13	0.65	0.84
CaO	9.77	5.79	5.01	4.10	4.16	3.92	3.52	3.18	2.33	1.80
Na_2O	0.75	5.47	5.06	4.66	4.36	4.08	5.22	4.63	4.55	4.65
K_2O	0.12	3.26	2.27	1.20	1.79	3.28	2.00	1.93	2.40	3.55
H_2O+	4.75	0.60	1.58	1.34	1.03	0.99	0.85	0.90	0.86	0.67
H_2O-	0.21	0.06	0.13	0.06	0.10	0.11	0.12	0.12	0.12	0.08
P_2O_5	0.08	0.36	0.31	0.19	0.14	0.26	0.19	0.15	0.09	0.13
Total	100.18	100.20	100.40	100.50	100.32	100.23	100.38	99.99	99.86	100.04

B. NIGGLI VALUES

	H1846	H642	H1124	H608	H1047	H1088	H1145	H1210	H1214	H1279
si	79	165	177	274	275	245	286	301	349	352
al	5.3	35.7	34.7	39.4	36.6	37.2	43.6	40.6	41.8	42.0
fm	74.9	23.9	29.0	20.8	23.6	23.8	13.3	19.3	16.0	15.1
c	18.4	18.4	16.6	17.8	18.0	16.1	16.2	14.8	12.5	9.5
alk	1.4	21.9	19.6	21.6	21.8	22.9	26.9	25.3	29.7	33.4
k	0.07	0.28	0.22	0.15	0.21	0.34	0.20	0.22	0.26	0.33
mg	0.79	0.43	0.43	0.43	0.46	0.41	0.48	0.38	0.29	0.43
c/fm	0.24	0.77	0.57	0.85	0.76	0.67	1.22	0.76	0.77	0.63

APPENDIX III

HOMOGENEOUS GRANITE

A. CHEMICAL ANALYSES

	H268	M492	H516A	H1272	H334	H540	H506	H857	H892	H1174	Grout
SiO_2	64.05	68.81	70.12	71.51	73.81	73.78	74.95	70.56	73.07	77.32	77.05
TiO_2	0.82	0.61	0.37	0.35	0.13	0.16	0.09	0.40	0.25	0.03	0.28
Al_2O_3	15.58	13.66	14.52	13.30	14.32	13.62	13.87	13.74	13.51	12.62	10.68
Fe_2O_3	0.89	0.63	0.94	1.99	0.49	0.69	0.39	1.08	1.08	0.61	1.10
FeO	4.31	3.02	1.60	1.45	1.07	0.97	0.62	2.56	1.12	0.33	1.71
MnO	0.09	0.02	0.07	0.03	0.03	0.24	0.04	0.26	0.03	0.01	0.03
MgO	1.07	1.21	1.00	1.01	0.38	0.26	0.25	0.40	0.37	0.23	0.34
CaO	2.44	3.25	2.21	2.10	1.02	1.15	1.05	1.64	0.50	1.12	0.93
Na_2O	4.50	3.42	4.30	4.70	4.01	3.13	4.04	2.53	2.71	3.74	2.52
K_2O	4.71	4.76	3.90	2.98	4.62	4.91	4.79	5.95	6.48	3.05	4.30
H_2O+	1.05	0.60	0.50	0.70	0.58	0.39	0.48	0.72	1.00	0.51	0.39
H_2O-	0.16	0.05	0.05	0.07	0.09	0.03	0.05	0.10	0.14	0.09	0.03
P_2O_5	0.34	0.10	0.40	0.12	0.04	1.02	0.02	0.08	0.10	0.05	0.29
Total	100.01	100.14	99.98	100.31	100.59	100.35	100.64	100.02	100.36	99.71	99.67*

* Also CO_2 0.22 per cent, ZrO_2 0.02 per cent and BaO 0.05 per cent

B. NIGGLI VALUES

	H268	M492	H516A	H1272	H334	H540	H506	H857	H892	H1174	Grout
si	255	303	334	341	406	424	426	356	415	485	505
al	36.4	35.3	40.5	37.2	46.2	45.9	46.1	40.7	45.2	46.8	41.3
fm	23.8	21.4	27.1	21.2	10.2	11.4	7.1	18.9	13.1	10.9	18.5
c	10.2	15.3	11.1	10.8	5.9	7.2	6.8	8.9	3.1	7.5	6.3
alk	29.6	28.0	31.3	30.8	37.6	35.5	40.0	31.4	38.6	35.0	33.9
k	0.41	0.47	0.37	0.29	0.43	0.51	0.44	0.61	0.61	0.35	0.53
mg	0.27	0.37	0.41	0.35	0.29	0.18	0.29	0.16	0.24	0.21	0.19
c/fm	0.42	0.71	0.41	0.51	0.58	0.63	0.95	0.42	0.26	0.69	0.34

APPENDIX IV

GRANITE PLUTONS

A. CHEMICAL ANALYSIS

	H872	H451	H532	Hamilton I	Hamilton II
SiO_2	69.52	73.76	70.03	78.78	78.07
TiO_2	0.67	0.25	0.50	0.12	0.20
Al_2O_3	13.52	13.19	13.97	11.62	10.65
Fe_2O_3	1.90	0.56	0.84	0.60	1.20
FeO	2.10	1.53	2.63	1.12	0.86
MnO	0.42	0.04	0.06	0.03	0.06
MgO	0.84	0.42	0.70	0.07	0.27
CaO	2.18	1.26	2.38	0.64	0.78
Na_2O	2.94	3.27	3.51	2.12	2.93
K_2O	4.78	5.19	4.85	4.66	4.75
H_2O+	1.09	0.53	0.46	0.34	0.47
H_2O-	0.03	0.09	0.11	0.06	0.03
P_2O_5	0.17	0.05	0.14	Tr	Tr
Total	100.16	100.14	100.18	100.16	100.27*

* Also Cl 0.10 per cent and F 0.03 per cent

B. NIGGLI VALUES

	H872	H451	H532	Hamilton I	Hamilton II
si	339	409	331	558	515
al	37.8	42.8	38.9	48.5	41.2
fm	22.8	13.6	18.2	10.6	14.3
c	11.2	7.6	12.2	5.3	5.6
alk	28.3	35.9	30.7	35.6	38.9
k	0.51	0.51	0.48	0.58	0.52
mg	0.12	0.27	0.27	0.08	0.19
c/fm	0.49	0.56	0.66	0.50	0.39

* *

KEY TO FIGURES

Figure 1 : The Granitic Rocks of Swaziland and the Eastern Transvaal.

Figure 2 : Locations of Chemically Analysed Granitic Rocks.

* *

THE GRANITIC ROCKS OF SWAZILAND AND THE EASTERN TRANSVAAL

10 0 10 20 30
Kilometres

SEDIMENTARY AND VOLCANIC ROCKS

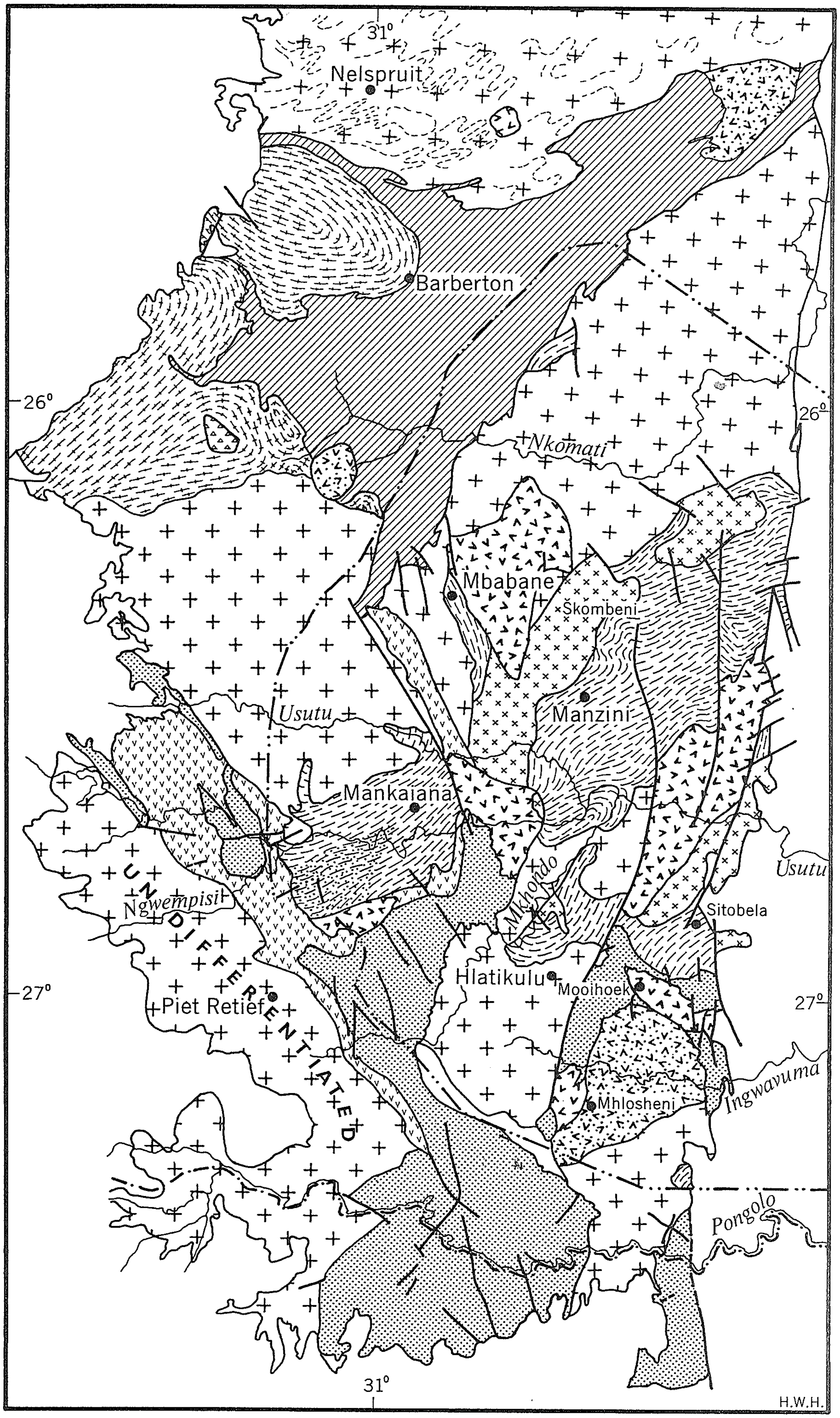
- Younger cover rocks (Transvaal and Karroo Sequences)
- Pongola Sequence
- Swaziland Sequence

GRANITIC ROCKS

- Younger Plutons
- Older Plutons
- Homogeneous Granite
- Nelspruit Migmatites
- Granodiorite Suite
- Diapiric Tonalite Domes
- Hornblende Tonalitic Gneiss } Ancient Gneiss Complex
- Leucotonalitic Gneiss, Metavolcanic and Metasedimentary Gneisses } Ancient Gneiss Complex

OTHER INTRUSIVE ROCKS

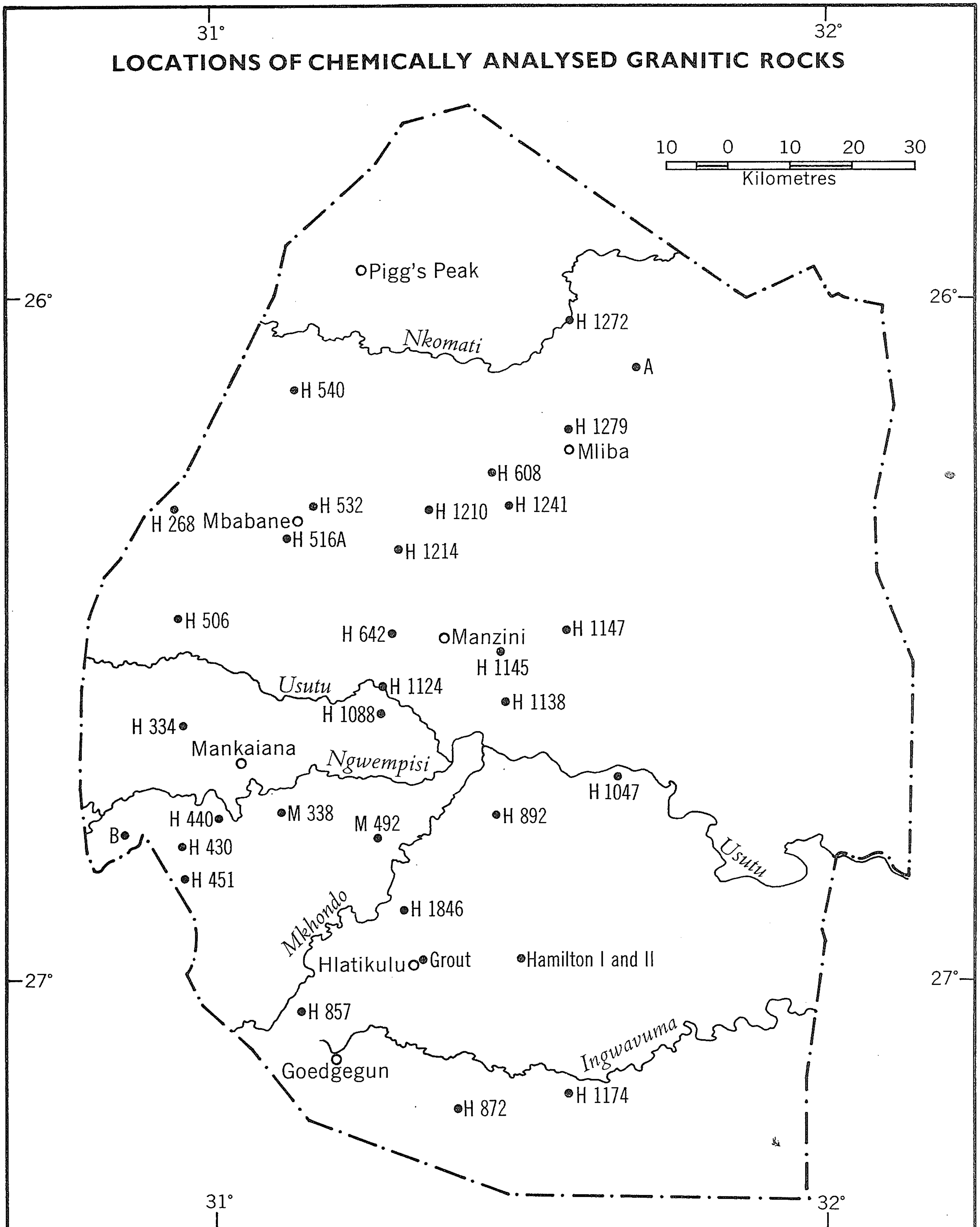
- Bosmankop Syenite
- Usushwana Complex
- Faults
- International Boundary
- Provincial Boundary



Geology of Transvaal and Natal modified after Viljoen and Viljoen (1969), and Geological Survey of South Africa 1:1,000,000 Geological Map.

Figure 1.

LOCATIONS OF CHEMICALLY ANALYSED GRANITIC ROCKS



TONALITIC GNEISSES		GRANODIORITE SUITE		HOMOGENEOUS GRANITE		PLUTONS
M 338	H 1241	H 1846	H 1088	H 268	H 506	H 872
H 440	A	H 642	H 1145	M 492	H 857	H 451
H 1138	H 430	H 1124	H 1210	H 516A	H 892	H 532
H 1147	B	H 608	H 1214	H 1272	H 1174	Hamilton I and II
		H 1047	H 1279	H 334	Grout	
				H 540		

Figure 2.

H.W.H.