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ABSTRACT

A total of 13 late granite plutons have now been recognized in the Archaean granite-greenstone terrane of the eastern Transvaal and Swaziland. These plutons, although characterized by diverse ages, origins and compositions, collectively represent the final magmatic event in the development of the Archaean granitic crust in the region. Five sub-types are defined, principally on the basis of compositional criteria, and these are :-

1. the Dalmein-type plutons which are granodioritic in composition, range in age between approximately 3,2-2,9 Ga, and probably formed by partial melting of pre-existing tonalitic or trondhjemitic gneisses;

2. the Boesmanskop-type plutons which are represented by a differentiated syeno-granite complex dated at between ≅ 3,1-2,8 Ga and are considered to have formed by melting of an intermediate (dioritic) parent under conditions of high confining pressure;

3. the Cunning Moor-type plutons which are tonalitic in composition, have been dated at approximately 2,8 Ga, and have an origin related either to fractionation from a Dalmein-type magma or partial melting of older tonalitic/trondhjemitic gneisses;

4. the Sicunusa-type plutons which are granitic in composition, have been dated at approximately 2,6 Ga, and formed by differentiation of a Dalmein-type magma in which K-feldspar was a liquidus phase and fO_2 was relatively low; and

5. the Mpageni-type plutons which are similar to the Sicunusa-type plutons in terms of bulk composition but are dated at approximately 2,5 Ga and formed by differentiation of Dalmein-type magma in which K-feldspar was not on the liquidus and fO_2 was higher than in the former case.

The presently available data provides a limited insight into the role and significance of these plutons in Archaean crustal evolution and additional studies are required.

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I. INTRODUCTION

The Archaean granitic terrane in the Barberton region and Swaziland is dominantly underlain by a suite of tonalite-trondhjemite gneisses and migmatites as well as areally extensive, coarse-grained-to-porphyritic, essentially potash-rich granodiorites and adamellites. The two suites have been ascribed respectively, to the first and second magmatic cycles or pulses responsible for the progressive secular cratonization of the Archaean sialic crust in this region (Anhaeusser and Robb, 1981). These early continent-building episodes were terminated by a third magmatic pulse, the characteristics of which are reviewed in this paper.

The granite plutons which form components of the third magmatic cycle or pulse are characterized by diversity in terms of their origins, ages of emplacement, composition and topographic expression in the field. The bodies were emplaced between approximately 3,2 Ga and 2,5 Ga and are represented by a variety of rock types which include tonalites, granodiorites, adamellites, granites and syenites. Despite their compositional range these plutons are characterized by a number of unifying features which serve to distinguish them from earlier granites in the region. They are all post-tectonic and typically show evidence of magmatic intrusion into the surrounding country rocks. Textures in these granites are all primary, massive, and hypidiomorphic, with only sporadic indications of an aligned mineral fabric which can usually be ascribed to magmatic flow. The intrusion of these plutons resulted in a sharp truncation of the surrounding fabric or layering and was accompanied by brittle fracture typically indicative of the emplacement of a liquid magma into a pre-heated conduit or structurally weakened zone. In contrast to the earlier potash-rich batholiths, for example, each of the late plutons consists essentially of a single, dominant rock component and are considered to have been derived from single magmatic pulses. Their size is therefore limited, and the largest of the plutons does not exceed 700 km² in extent (Hunter, 1968). Their shape is often elongated along one axis and this has been shown to coincide with known regional structural trends (Hunter, 1968).

Little detailed work has been undertaken on the late granite plutons although they are commonly referred to in geological accounts of the region (van Eeden, 1941; Visser *et al.*, 1956; Visser and Verwoerd, 1960). Hunter (1968) provided detailed geological descriptions of the Swaziland plutons and also presented some of the earliest chemical analyses of these rocks. Viljoen and Viljoen (1969) and Hunter (1973) provided classifications of the Archaean granites in the Barberton and Swaziland regions in which the late plutons were collectively recognized as the final event in the evolution of this terrane. Some geochronological work by de Gasparis (1967), Oosthuyzen (1970) and Davies (1971) led to the recognition of an older (3,2-2,9 Ga) and a younger (2,6-2,5 Ga) period of formation of the late plutons. Petrogenetic considerations of these bodies are limited to studies by Condie and Hunter (1976) and Glikson (1976). The former of these, in particular, presented much new geochemical data, mainly from the Swaziland plutons, and provided the first detailed attempt at petrogenetic modelling of this suite of rocks.

II. GEOLOGICAL CHARACTERISTICS

A total of 13 late granitoid plutons are now recognized in the Archaean granitic terrane of the Barberton region and Swaziland (Fig. 1). Certain of these bodies are unique in the region both in terms of their composition as well as other characteristics to be described later. Others clearly form part of a family containing a number of plutons with markedly similar chemical traits. In this paper it is suggested that the 13 granitoid bodies can be grouped into five pluton-types, three of which were previously recognized by Condie and Hunter (1976), whereas the other two types have emerged from studies carried out during the Geodynamics Project. The following sections briefly summarize the geological characteristics of the various pluton-types.

A. Dalmein-type Plutons

These plutons, of which there are three, collectively represent the oldest group and are typically characterized by granodioritic compositions.

1. *Dalmein Pluton*

This granodioritic body intrudes and abruptly truncates metavolcanic and metasedimentary successions of the Hooggenoeg and Kromberg formations in the southwestern extremity of the Barberton greenstone belt. The southwestern contact of the pluton, where exposed, is juxtaposed with a medium-grained granodioritic phase of the Mpuluzi batholith. Exposure here does not permit the relative ages of these two phases to be established. The Dalmein granodiorite is typically porphyritic, containing large euhedral crystals of zoned plagioclase, poikilitic microcline megacrysts and quartz. Biotite, chlorite, epidote, sphene and zircon occur as minor or accessory mineral components. The development of phenocrysts is variable over the body and in certain areas no megacrysts occur. The pluton is characterized by numerous, small amphibolitic remnants and in the southern part of the body these are particularly prominent, imparting a migmatitic appearance to the rock. In general, however, and particularly along the northern flank of the Dalmein pluton, no evidence was found for the gross incorporation of greenstone material into the magma.

2. *Salisbury-Kop Pluton*

This pluton, which intrudes and truncates rocks of both the Moodies and Onverwacht groups, occurs at the northeastern extremity of the Barberton greenstone belt and is typically more leucocratic than the Dalmein pluton (see Table 1). It also contains slightly more K-feldspar than the latter (Viljoen and Viljoen, 1969) and

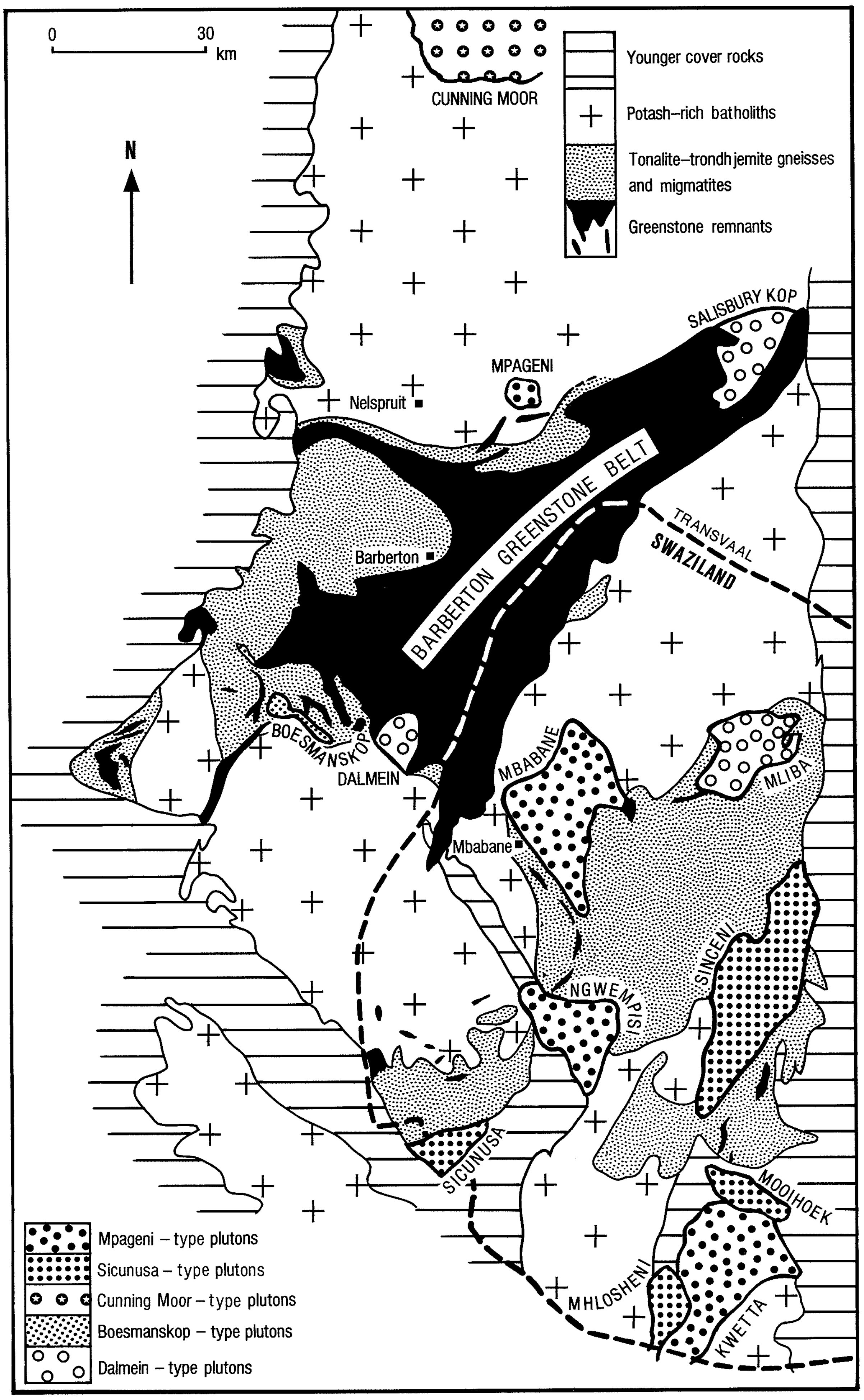

Figure 1 : Simplified geological map showing the distribution of the 13 late granite plutons in the eastern Transvaal and Swaziland and their classification into five pluton sub-types.

exhibits a less well-developed porphyritic texture. Despite these differences, however, the overall appearance of the two bodies is otherwise very similar.

3. *Mliba Pluton*

The Mliba pluton, which is granodioritic in composition and texturally uniform throughout intrudes tonalite-trondhjemite gneisses and migmatites as well as scattered greenstone remnants of the Ancient Gneiss Complex in central Swaziland. The rock is coarse-grained and massive with a crude alignment of feldspar grains occurring only at its extreme edge (Hunter, 1968). Its major constituents are quartz, plagioclase and microcline together with subordinate biotite and accessory amounts of allanite, epidote, zircon and apatite.

TABLE 1

LATE POST-TECTONIC GRANITE (*SENSU LATO*) PLUTONS IN THE BARBERTON MOUNTAIN LAND AND SWAZILAND

		DALMEIN-TYPE					BOESMANSKOP-TYPE			CUNNING MOOR-TYPE		SICUNUSA-TYPE				MPAGENI-TYPE			
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	SiO_2	69,30	70,15	69,47	72,30	70,80	59,04	64,58	66,82	68,97	71,47	74,00	74,20	77,50	78,42	73,20	70,50	68,60	69,00
	TiO_2	0,37	0,34	0,33	0,22	0,32	1,04	0,78	0,68	0,36	0,26	0,29	0,21	0,11	0,16	0,26	0,32	0,58	0,66
	Al_2O_3	14,80	14,79	15,40	14,00	14,60	15,08	15,41	14,37	15,80	15,36	13,10	13,40	12,10	11,14	13,80	14,20	13,80	14,30
	Fe_2O_3*	2,84	2,37	2,62	1,62	2,28	6,83	4,53	4,18	2,52	1,71	2,28	1,83	1,30	0,90	1,87	2,34	3,78	2,28
	MnO	-	0,05	0,06	-	-	0,17	0,12	0,04	0,06	0,03	-	-	-	0,04	-	-	-	-
wt. %	MgO	1,03	0,96	0,95	0,64	0,75	2,15	1,19	1,83	1,61	0,87	0,33	0,28	0,11	0,17	0,45	0,59	0,67	0,80
	CaO	2,22	1,88	2,41	1,63	2,24	3,79	2,82	2,07	2,72	3,14	1,21	0,93	0,41	0,71	1,40	2,25	2,17	2,33
	Na_2O	4,76	4,73	4,29	5,08	4,66	4,15	4,36	3,29	4,98	4,14	3,33	3,20	2,77	2,53	3,54	3,28	4,25	3,21
	K_2O	3,23	3,20	3,09	3,54	3,29	5,48	4,96	4,79	2,13	1,50	4,98	5,51	5,13	4,71	5,03	5,71	5,13	4,85
	P_2O_5	-	0,18	0,18	-	-	0,73	0,52	0,27	0,01	0,08	-	-	-	0,01	-	-	-	-
	L.O.I.	-	1,04	0,58	-	-	0,75	0,51	0,83	0,45	1,27	-	-	-	0,45	-	-	-	-
	TOTALS	99,55	99,67	99,38	99,03	98,94	99,21	99,78	99,17	99,61	99,83	99,52	99,56	99,43	99,24	99,55	99,19	98,98	99,44
	Rb	105	112	86	97	63	190	230	228	62	48ψ	298	269	267	-	256	266	184	216
	Sr	692	503	583	350	565	1620	1530	1169	522	366ψ	93	71	17	-	315	238	343	328
	Ba	880	620	672	592	767	1750	1700	1050	427	-	454	360	300	-	834	1200	1430	1150
	La	63	52	53	32	29	154	124	98	-	-	96	95	58	-	124	142	143	108
	Ce	126	78	105	65	56	283	205	213	-	-	183	180	114	-	232	227	250	206
ppm	Nd	-	35	41	-	-	109	73	64	-	-	-	-	-	-	-	-	-	-
	Sm	8,6	6,6	7,5	4,8	3,9	26	16	14	-	-	12	11	14	-	13	13	16	14
	Eu	2,0	1,7	2,0	0,74	0,73	6,1	3,2	3,9	-	-	0,83	0,75	0,77	-	1,9	1,6	2,0	2,2
	Tb	0,45	0,53	1,14	0,43	0,31	2,2	1,4	1,5	-	-	1,90	1,20	3,20	-	1,20	1,30	1,80	2,00
	Yb	1,40	1,04	1,70	1,10	0,63	3,5	2,6	3,1	-	-	5,50	1,40	11,0	-	2,60	2,60	3,90	5,00
	Lu	0,19	-	0,19	0,20	0,10	0,3	0,2	0,2	-	-	0,76	0,22	1,3	-	0,30	0,39	0,52	0,50

* (Fe_2O_3 - Total iron as Fe_2O_3) ψ (Hawkesworth et al., 1975)

DALMEIN-TYPE - Column A - Dalmein - average of 2 analyses after Condie and Hunter (1976).
B - Dalmein - average of 2 analyses after Glikson (1976).
C - Dalmein - average of 10 analyses, Table 2.
D - Salisbury Kop - average of 2 analyses after Condie and Hunter (1976).
E - Mliba - average of 3 analyses after Condie and Hunter (1976).

BOESMANSKOP-TYPE - F - Boesmanskop syenite
G - Boesmanskop quartz-syenite
H - Kees Zyn Doorns syeno-granite
} data from Anhaeusser et al. (1979)

CUNNING MOOR-TYPE - I - Cunning Moor - average of 9 analyses after Robb (1978).
J - Sesombi (+) - data from Harrison (1970).

SICUNUSA-TYPE - K - Sicunusa pluton, average of 3 analyses after Condie and Hunter (1976).
L - Sinceni pluton, average of 3 analyses after Condie and Hunter (1976).
M - Mhlosheni pluton, average of 3 analyses after Condie and Hunter (1976).
N - Mooihoek pluton, average of 2 analyses after Hunter (1968).

MPAGENI-TYPE - O - Mpageni - average of 2 analyses after Condie and Hunter (1976).
P - Mbabane - average of 3 analyses after Condie and Hunter (1976).
Q - Ngwempisi - average of 4 analyses after Condie and Hunter (1976).
R - Kwetta - average of 3 analyses after Condie and Hunter (1976).

(+) Sesombi tonalite pluton, 35 km northwest of Que Que, Zimbabwe.

B. Boesmanskop-type Plutons

The Boesmanskop syeno-granite complex is the only suite of its kind in the Barberton-Swaziland region and occurs a few kilometres southwest of the Barberton greenstone belt. The body intrudes tonalite-trondhjemite gneisses and migmatites as well as scattered greenstone remnants in well-exposed terrane associated with the first magmatic cycle. The Boesmanskop complex comprises two discrete plutons which show a range in compositions from syenite through quartz-syenite and granite (Anhaeusser *et al.*, 1979, and in press). The main Boesmanskop syenite pluton is coarse-grained-to-porphyritic and consists essentially of syenites and quartz-syenites. These rocks consist dominantly of orthoclase perthite, plagioclase, hornblende, augite, biotite (± quartz) with accessory amounts of apatite, magnetite, epidote, zircon and sphene. Attached to the main pluton is a linear appendage of leucocratic, finer-grained syeno-granite (the Weergevonden body) which consists essentially of microcline microperthite, plagioclase and minor quartz together with traces of epidote and muscovite. The second pluton, known as the Kees Zyn Doorns body, occurs a few kilometres northwest of the Boesmanskop pluton and is also coarse-grained-to-porphyritic, containing orthoclase perthite and plagioclase, with varying amounts of quartz, hornblende and biotite.

The Boesmanskop syeno-granite complex was emplaced along a major northwest-trending lineament which extends for over 50 km into Swaziland (Anhaeusser *et al.*, 1979, and in press). Also emplaced along this lineament was the Ngwempisi pluton and the ∿ 2,8 Ga Usushwana Complex, the latter being a differentiated mafic-to-felsic intrusive suite.

C. Cunning Moor-type Plutons

The Cunning Moor pluton was recently recognized in the poorly-exposed, flat-lying terrane to the east of Bushbuckridge (Robb, 1977). It is dominantly tonalitic in composition and is the only body of its age and type in the Barberton and Swaziland region. The pluton comprises a grey, massive, medium-to-coarse-grained rock consisting predominantly of plagioclase and quartz with lesser amounts of biotite, microcline and sphene. Accessory amounts of rutile, zircon, apatite and muscovite are also present.

The Cunning Moor pluton is intruded into the marginal potash-rich gneisses and migmatites of the Nelspruit batholith (Fig. 1). Although the contact is not well-exposed, in places veins of tonalite intrude the Nelspruit migmatites and gneisses. It is interesting to note that in the Archaean terrane of Zimbabwe, a pluton of similar age and composition known as the Sesombi tonalite, intrudes the Que Que greenstone belt. These, younger tonalite plutons, which differ significantly from the older, more intensely deformed, tonalite gneiss plutons, have, therefore, been documented in other Archaean terranes but are rare.

D. Sicunusa-type Plutons

These plutons, of which there are four, all occur in south-central Swaziland (Fig. 1). They are all topographically prominent and are typically grey-to-pink and coarse-grained or porphyritic. Compositionally, they are granites (*sensu stricto*) or adamellites and consist predominantly of potash feldspar, quartz, plagioclase and biotite together with minor amounts of sphene, zircon, allanite, magnetite and apatite (Hunter, 1968). The plutons which fall into this group are described below.

1. *Sicunusa Pluton*

This pluton intrudes and, therefore, post-dates the gabbroic and granophyric rocks of the ≅ 2,8 Ga Usushwana Complex and abruptly terminates the southwest-trending igneous layering in this body. The northern flank of the pluton is also intrusive into gneisses and migmatites of the Ancient Gneiss Complex whereas the southern contact was emplaced into volcanic rocks of the Nsuze Group which have been dated at 3,09 ± 0,09 Ga (Burger and Coertze, 1973).

2. *Sinceni Pluton*

The Sinceni pluton is one of the largest of the late granite plutons and forms an elongate-shaped body which is emplaced approximately along the contact between units of the Ancient Gneiss Complex and phases of an, as yet un-named, potash-rich batholith (Fig. 1). The pluton is laterally bisected by a major, north-south-trending shear zone which locally modifies the appearance of the granite. The northern margin of the pluton consists of a medium-grained leucocratic rock which contrasts with the more typical coarse-grained texture in the body (Hunter, 1968).

3. *Mhlosheni Pluton*

The Mhlosheni body has a distinctive grey colour, is typically coarse-grained and is generally not porphyritic. It is also somewhat more leucocratic than most of the late granite plutons. Along its northern flank the pluton is intruded into shales and quartzites of the Mozaan Group, the latter being baked and recrystallized near to the contact (Hunter, 1968). The eastern flank of the Mhlosheni pluton abuts against the Kwetta body which has in the past been regarded as being older than the former (Swaziland, 1:125 000 Geological Map, compiled by D.R. Hunter, 1966). The Kwetta pluton is, however, currently correlated with the Mpageni-type plutons (Condie and Hunter, 1976) for which there is evidence of their being younger than the Sicunusa-type (see later and Table 3). As such, some doubt must exist as to the exact relationship between the Kwetta and Mhlosheni plutons.

4. *Mooihoek Pluton*

The Mooihoek pluton, about which very little has been written, is very similar in all respects to the Mhlosheni body and, likewise, intrudes the Mozaan Group as well as abutting against the Kwetta pluton along its southern flank (Fig. 1).

E. Mpageni-type Plutons

Grouped into this category are four plutons which occur both to the north and south of the Barberton greenstone belt. They are arranged in a broadly linear array which extends for approximately 150 km (Fig. 1). Collectively, they are regarded as the youngest of the late granite plutons although only the Mpageni pluton itself has been reliably dated (Table 3). In view of the doubtful age relationships between the Kwetta pluton and the apparently older Sicunusa-type bodies it is also possible that the Mpageni group, although being compositionally similar, were emplaced over an extended period of time. Like the Sicunusa-type bodies, the Mpageni plutons are characterized by granitic (*sensu stricto*) compositions, are typically coarse-grained or porphyritic and are topographically prominent.

1. *Mpageni Pluton*

The Mpageni pluton occurs approximately 12 km north of the Barberton greenstone belt where it intrudes and abruptly truncates potash-rich gneisses and migmatites associated with the Nelspruit batholith. The granite is generally pink and coarse-to-very coarse-grained but is generally not porphyritic. It consists dominantly of quartz, microcline and oligoclase, in approximately equal proportions, together with minor biotite and accessory apatite, zircon and tourmaline (Visser and Verwoerd, 1960; D.A. van Nierop, unpubl. data). The Mpageni pluton has two phases of fine-grained grey syenite associated with it and these occur as dykes both within the body and emplaced as ring dykes surrounding it. The pluton is also characterized by a thin, irregular, metasomatic halo which is demarcated by large isolated, reddish megacrysts of poikiloblastic K-feldspar.

2. *Mbabane Pluton*

The Mbabane pluton is one of the largest of the late granite plutons and forms prominent hilly terrain to the northeast of Mbabane, Swaziland. The pluton intrudes gneisses and migmatites of the Ancient Gneiss Complex along its southern margin and homogeneous, massive adamellites associated with the second magmatic cycle, along its northern contact (Fig. 1). The body is essentially coarse-grained-to-porphyritic and is characterized by the common occurrence of partially assimilated mafic inclusions which range from a few centimetres to several metres in size (Hunter, 1968). The main components of the granite include microcline perthite, plagioclase and quartz, together with minor biotite and occasional hornblende crystals in the more mesocratic phases of the pluton.

3. *Ngwempisi Pluton*

The Ngwempisi pluton is intruded into a variety of rock types in south-central Swaziland. These include gabbros and granophyres of the Usushwana Complex, sediments and volcanic rocks of both the Nsuze and Mozaan groups, gneisses and migmatites of the Ancient Gneiss Complex and homogeneous granodiorites and adamellites associated with the second magmatic cycle. Its geological characteristics are otherwise identical to those of the Mbabane pluton.

4. *Kwetta Pluton*

The geological relationships between the Kwetta pluton and the surrounding rock types are unclear and it is only relatively recently that this body has been included in the category of late granite plutons (Condie and Hunter, 1976). Although compositionally similar to other Mpageni-type plutons (see Table 1), the Kwetta body was previously classified as being intermediate in age between the batholiths of the recently defined second magmatic cycle and the late plutons of the third magmatic cycle (i.e. Ag4 granite on the Swaziland 1:125 000 Geological Map compiled by D.R. Hunter, 1966). As mentioned previously, the Mpageni-type plutons are regarded as being the youngest of the late granite plutons (see Table 3) and, as such, the Kwetta pluton does not appear to be directly correlatable with the latter. Few, if any, geological accounts of the body are available and it is described merely as a massive, porphyritic granite. The inclusion of the Kwetta body into the Mpageni group is justified at this stage by compositional similarities but further field and geochronological studies are needed to confirm this classification.

III. MAJOR AND TRACE ELEMENT CHARACTERISTICS

The classification of the late granite plutons into five sub-types is based principally on their compositional characteristics as well as certain diagnostic geological and field criteria. Averaged data for each of the 13 plutons, is presented in Table 1 and it is evident that the five sub-types are compositionally distinctive.

The Dalmein-type plutons are mainly granodioritic in composition and are characterized by K_2O/Na_2O ratios in the range 0.68-0,72. Average Rb contents vary between 63-112 ppm whereas Sr values range between 350-690 ppm. Rb/Sr ratios are typically 0,11-0,28 and Ba contents average approximately 700 ppm.

The Boesmanskop-type plutons are best described as differentiated syeno-granite complexes and although syenitic and quartz-syenitic compositions predominate, rocks of granitic (*sensu stricto*) composition are also found (Anhaeusser *et al.*, 1979, and in press). SiO_2 contents in typical syenites may be as low as ≅ 59%, with total Fe_2O_3 + MgO approximately 8-9%. Quartz-syenites and granites have higher SiO_2 contents in the range 65-70% with concomitantly lower ferromagnesian abundances. K_2O/Na_2O ratios are high in all the rock types (1,1-1,5) as are the Rb (190-230 ppm), Sr (1170-1620 ppm) and Ba (1050-1759 ppm) contents when compared with other late granite plutons.

The Cunning Moor-type plutons are essentially tonalitic in composition and are characterized by relatively low K_2O/Na_2O ratios in the range 0,36-0,43. Rb contents are markedly lower than most other late granite plutons (48-62 ppm) and Rb/Sr ratios are typically 0,11-0,13.

The Sicunusa- and Mpageni-type plutons are both essentially granitic (*sensu stricto*) in composition although subtle differences exist in their major element chemistry (Table 1). The Sicunusa-type plutons have, for example, significantly higher SiO_2 contents (74-78%) than the Mpageni-type plutons (69-73%) whilst, conversely, the Mpageni-type plutons generally have slightly higher ferromagnesian contents than the Sicunusa-types. Values of CaO are also markedly higher in the Mpageni-type plutons but K_2O/Na_2O ratios in both sub-types are similarly high, being in the range 1,5-1,9. Rubidium abundances are only marginally higher in the Sicunusa-type plutons than in the Mpageni-types but a significant difference is evident in the amount of Sr present in the two sub-types. The Sicunusa plutons have very low average Sr contents (17-93 ppm) in comparison to other late granite plutons, whereas the Mpageni-type bodies exhibit significantly higher values in the range 240-340 ppm. Rb/Sr ratios are, therefore, significantly different in the two sub-types, being in the range 3,2-15,7 in the Sicunusa plutons, and 0,53-1,12 in the Mpageni plutons.

The chemical characteristics of the various pluton sub-types are diagrammatically summarized in Figs 2 and 3. Figure 2, which is a ternary plot of (Fe_2O_3*+MgO)-Na_2O-K_2O, illustrates the compositionally discrete fields of the various sub-types and outlines a broad trend involving the sequence tonalite-granodiorite-granite in four of the pluton groups. The Boesmanskop-type plutons do not fall on this trend and are clearly more ferromagnesian than the other late granite plutons. Figure 3 is a plot of averaged Rb v Sr and similarly defines a trend involving the sequence tonalite-granodiorite-granite. This trend exhibits an inverse relationship between Rb and Sr in four of the pluton sub-types with the tonalitic end-member having relatively high Sr and low Rb values and vice versa for the granitic (Sicunusa-type) end-member. Again the Boesmanskop-type plutons are quite distinct from this trend and are characterized by moderately high Rb abundances and extremely high Sr contents.

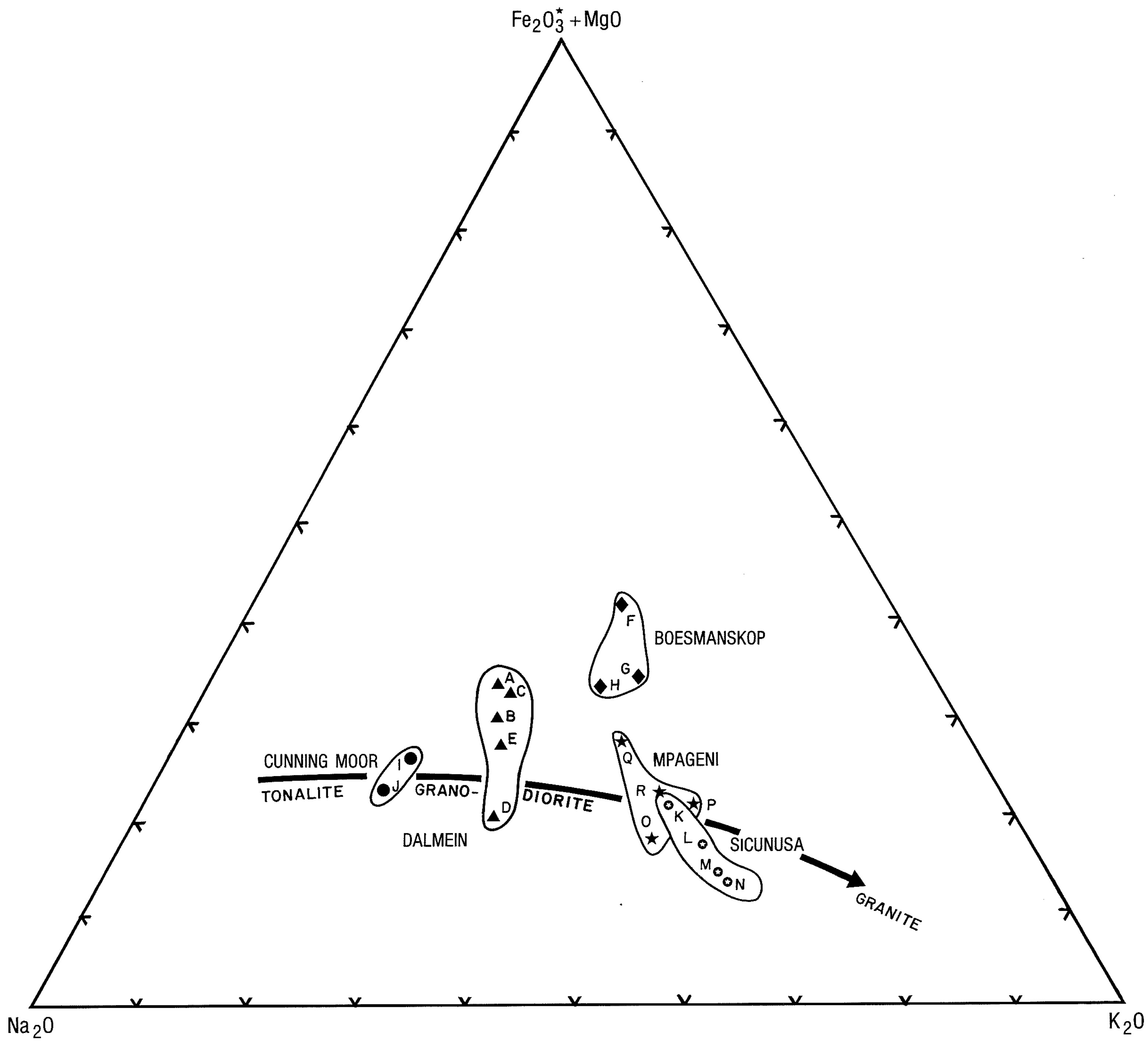

Figure 2 : Ternary (Fe_2O_3 + MgO) – Na_2O – K_2O diagram showing averaged data for the late granite plutons. The points A-R refer to the analyses listed in Table 1.*

A. Compositional Differences Within Individual Plutons

The discussion above has revolved around a consideration of the average compositions of each of the 13 plutons. This approach, whilst useful in categorizing these plutons, is restrictive in a genetic sense where it is necessary to consider the full range of compositions within any one magmatic body. Most of the plutons are represented by only a few samples which are unlikely to adequately reflect any possible crystal-liquid fractionation processes in these bodies. However, the Dalmein and Boesmanskop plutons have been mapped in detail and are covered by a comparatively representative suite of samples. The data pertaining to the Boesmanskop syenogranite complex is discussed in detail by Anhaeusser *et al.* (1979, and in press). The following section briefly considers the nature of systematic compositional variations in the Dalmein pluton.

Geochemical data pertaining to the Dalmein pluton is presented in Table 2, whilst the distribution of sample localities is shown on the geological map of the body in Fig. 4A. The Dalmein pluton exhibits a significant range in composition with SiO_2 varying between 66,69-72,41% and Fe_2O_3*+MgO between 1,90-4,46%. K_2O/Na_2O ratios are, however, relatively constant (0,5-1,0) and are broadly consistent with a granodioritic composition. When these chemical variations are presented in contour diagrams (Figs. 4B-G) it is apparent that these changes are regionally systematic. The plots of SiO_2 and Fe_2O_3*+MgO are conversely related and show that the pluton is enriched in silica and depleted in ferromagnesian content towards its margins. K_2O values are depleted towards the central portions of the pluton whereas CaO reflects the distribution of ferromagnesian components and is slightly depleted towards the margins of the body. The distributions of Rb and Sr are very similar to those of K_2O and CaO respectively, with Rb being depleted towards the centre of the pluton and Sr showing a tendency for depletion on its edges.

Chemical distributions over a single magmatic body, such as that described above, are usually interpreted in terms of *in situ* crystal fractionation processes. These processes may vary considerably and result either from the progressive inward nucleation of crystal growth (Wolhuter, 1973; McCarthy and Robb, 1978; Bateman and Nokleberg, 1978; Bateman and Chappell, 1979) or from subtle, gravitation- or convection-induced, crystal settling (Emeleus, 1963; Taylor, 1976; Robb, 1981). In certain cases patterns of distribution may be modified as a result of structural readjustments (tectonic folding or diapirism) subsequent to the solidification of the granite body (Taylor, 1976; Robb, 1981).

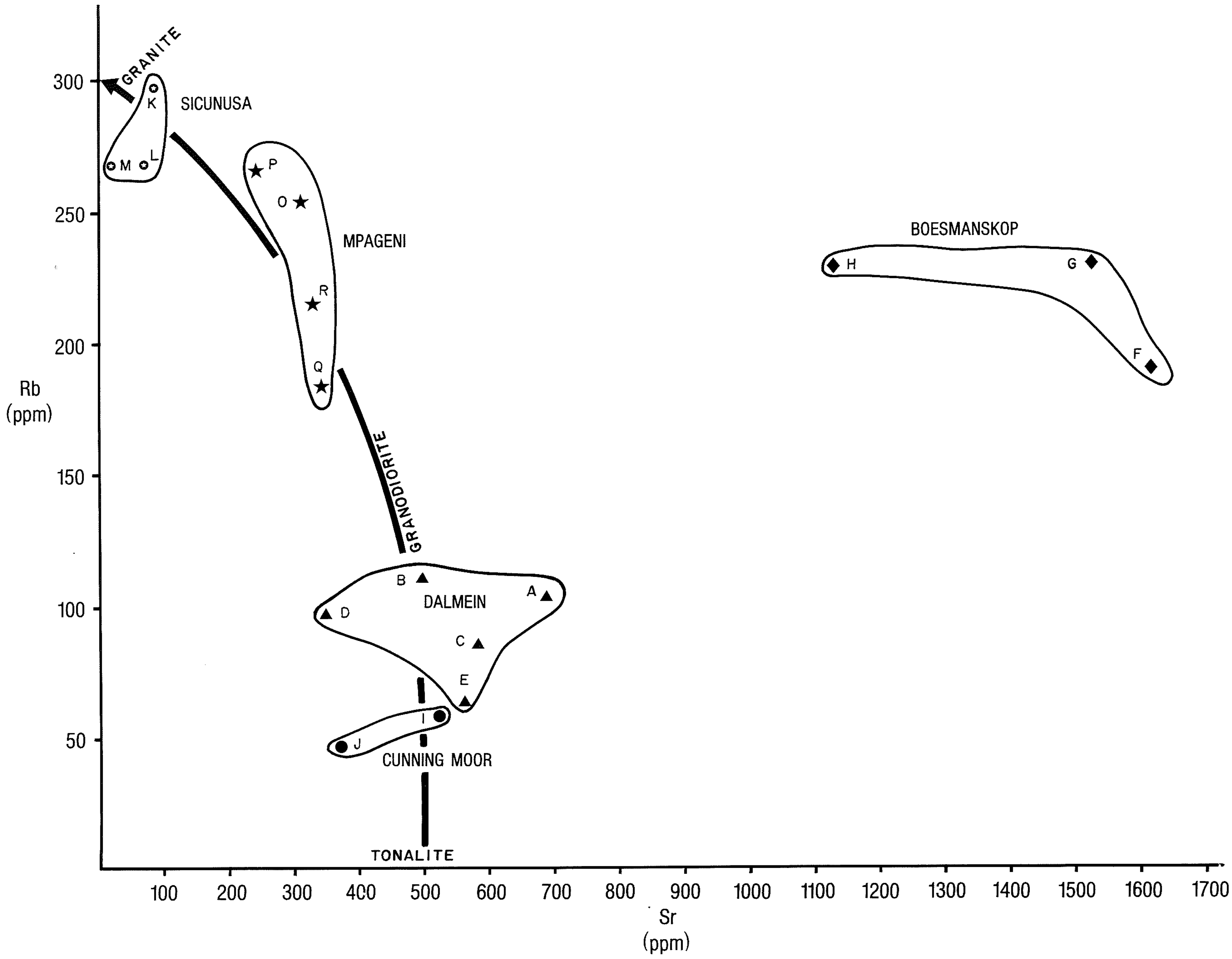

Figure 3 : Plot of Rb against Sr for averaged data representing the late granite plutons. The points A-R refer to the analyses listed in Table 1.

TABLE 2

CHEMICAL ANALYSES OF SAMPLES FROM THE DALMEIN PLUTON, SOUTHWEST OF THE BARBERTON GREENSTONE BELT

Sample	DP1	DP2	DP3	DP4	DP5	DP6	DP8B	DP9	DP11	DP12(i)	DP12(ii)
SiO_2	69,02	72,41	69,32	70,03	69,25	67,80	73,35	69,34	66,69	69,79	69,80
TiO_2	0,32	0,18	0,32	0,32	0,31	0,35	0,26	0,39	0,39	0,36	0,38
Al_2O_3	16,15	14,69	15,20	15,08	15,15	14,87	14,89	15,91	15,77	15,72	15,30
Fe_2O_3*	2,75	1,47	2,87	2,46	2,60	2,93	1,89	3,05	3,16	2,86	2,69
MnO	0,06	0,05	0,03	0,04	0,03	0,10	0,07	0,05	0,08	0,04	0,05
MgO	1,04	0,43	0,96	0,96	0,79	1,11	0,51	1,26	1,30	0,97	1,70
CaO	2,88	1,61	2,55	1,83	2,34	2,93	1,59	2,57	2,85	2,79	2,76
Na_2O	4,13	3,64	4,42	4,34	4,06	4,94	3,88	4,43	4,33	4,32	4,10
K_2O	2,49	3,84	2,42	3,67	3,84	2,81	4,47	2,79	2,95	3,10	2,89
P_2O_5	0,17	0,06	0,18	0,16	0,21	0,24	0,09	0,26	0,25	0,22	0,20
L.O.I.	0,68	0,32	0,48	0,63	0,44	0,74	0,89	0,55	0,37	0,49	0,66
TOTALS	99,70	98,60	98,75	99,52	99,02	98,82	100,89	100,60	98,14	100,66	100,53
Rb	42	63	54	96	104	85	141	118	115	-	74
Sr	675	312	593	522	618	670	207	732	735	-	618
Ba	515	814	298	777	1179	567	562	864	692	-	772
La	51,0	40,3	-	-	69,6	58,2	-	-	48,1	-	-
Ce	105,1	74,4	-	-	120,8	113,5	-	-	112,9	-	-
Nd	43,7	27,2	-	-	41,8	42,0	-	-	50,1	-	-
Sm	7,1	6,0	-	-	8,0	8,1	-	-	8,4	-	-
Eu	2,14	1,37	-	-	1,98	2,12	-	-	2,34	-	-
Tb	1,09	0,92	-	-	1,04	1,29	-	-	1,38	-	-
Yb	1,65	1,54	-	-	1,55	1,75	-	-	1,99	-	-
Lu	0,17	0,16	-	-	0,19	0,19	-	-	0,24	-	-

*(Fe_2O_3 - Total iron as Fe_2O_3
Analyses by L.J. Robb, Department of Geology, University of the Witwatersrand
DP12(ii) duplicate analysis by Bergström and Bakker, Johannesburg)

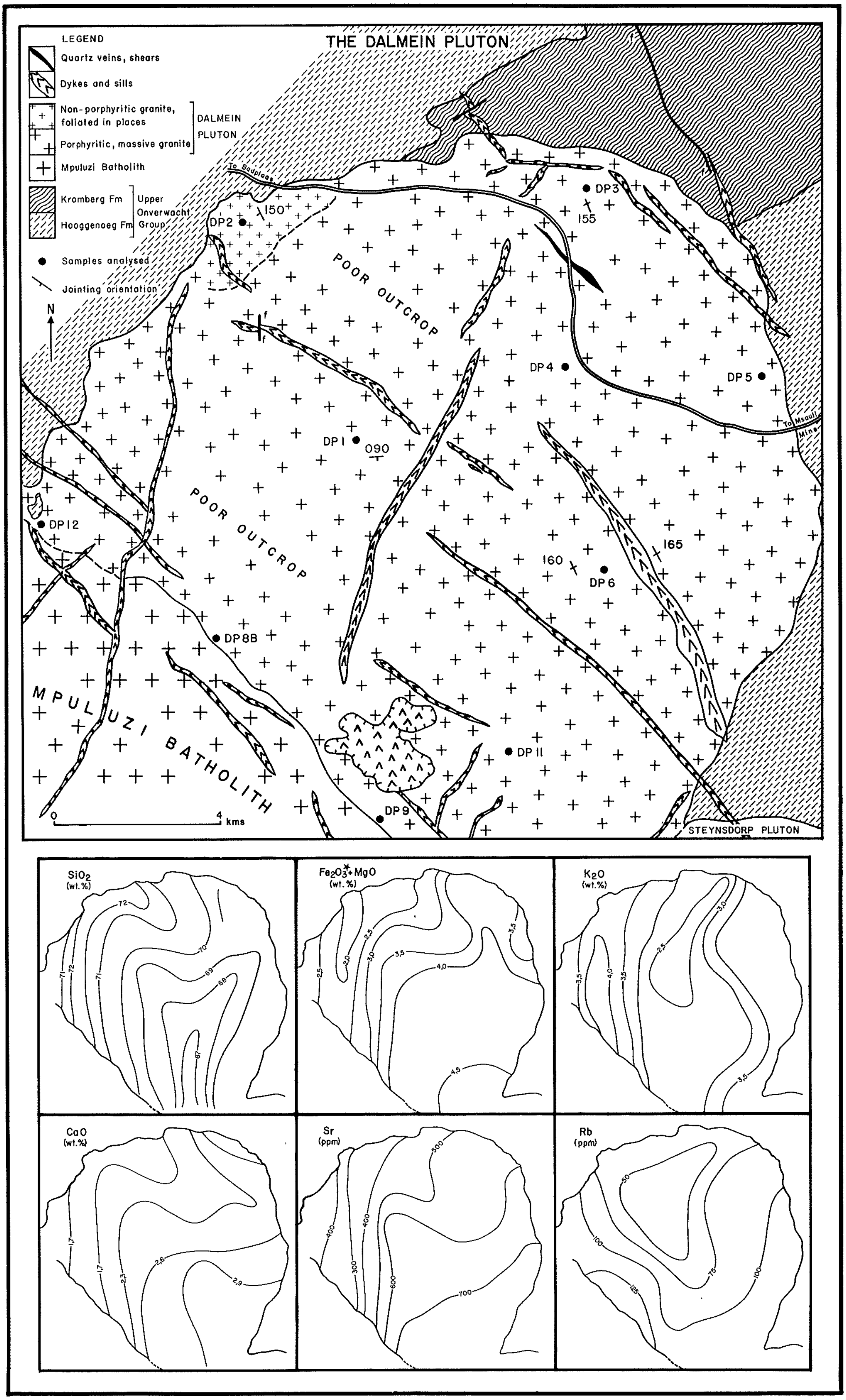

Figure 4 : A. *Simplified geological map of the Dalmein pluton in the southwestern portion of the Barberton greenstone belt.*

B–G. *Contour maps for SiO_2, Fe_2O_3* + MgO, K_2O, CaO, Sr, and Rb, respectively, over the Dalmein pluton.*

The systematic distribution of key granitophile elements over the Dalmein pluton is probably due to *in situ* crystal fractionation although it is not clear how the process occurred in this case. During simple inward nucleation of crystal growth there is a tendency for potassium and incompatible trace elements (i.e. Rb) to be concentrated into the centre of the progressively solidifying body. Similarly, typical fractionation trends usually invoke the early crystallization of mafic minerals such that later differentiates are more leucocratic than earlier ones. Clearly, inward nucleation of crystals does not appear to have occurred in the Dalmein pluton as the reverse of these trends is evident. Crystal fractionation may, therefore, have had a tendency to be horizontally induced, with the present compositional differences at surface being possibly due to slight tilting and subsequent erosion of the pluton. It is interesting to note that the contour diagrams for CaO and Sr in particular (Fig. 4E, F) are compatible with this suggestion. In all likelihood, however, crystal fractionation in the Dalmein pluton was a complex affair and cannot be fully resolved with the low-density sampling currently available.

The purpose of this discussion has been to point out that significant compositional differences do occur within the late granite plutons and these are probably the result of fractionation. This trend is particularly evident in the Boesmanskop syeno-granite complex where both crystal and liquid fractionation processes have resulted in compositions in the range syenite-quartz syenite-granite (Anhaeusser *et al.*, 1979, and in press). It is likely that the other plutons being considered exhibit similarly diverse compositional ranges (e.g. the Mpageni pluton, see earlier) and this aspect requires additional study.

IV. RARE EARTH ELEMENT CHARACTERISTICS

Rare earth element (REE) data are available for most of the late granite plutons with the exception of the tonalitic Cunning Moor pluton north of the Barberton greenstone belt (Table 1). As seen in the chondrite-normalized plots of Figs. 5 and 6, the REE patterns clearly distinguish and confirm four of the five pluton sub-types defined earlier on the basis of major and trace element abundances.

The Dalmein-type plutons are characterized by moderate light REE enrichment (La, 150-250 x over chondrites), insignificant-to-small negative Eu anomalies and depleted heavy REE ($\cong$ 10 x enriched over chondrites). Certain samples from the Dalmein pluton (Fig. 7) and the averaged data for the Salisbury Kop pluton (Fig. 5) exhibit a small negative Eu anomaly but the remainder of the Dalmein-type patterns do not show this feature.

The Boesmanskop-type plutons are characterized by significant light REE enrichment (La, 400-600 x over chondrites), heavy REE that are approximately 20-40 x enriched over chondrites and Ce_N/Yb_N ratios in the order of 20. The majority of these rocks exhibit no Eu anomaly (Fig. 5) although portions of the more leucocratic Weergevonden syenite are characterized by a negative Eu anomaly (Anhaeusser *et al.*, 1979, and in press).

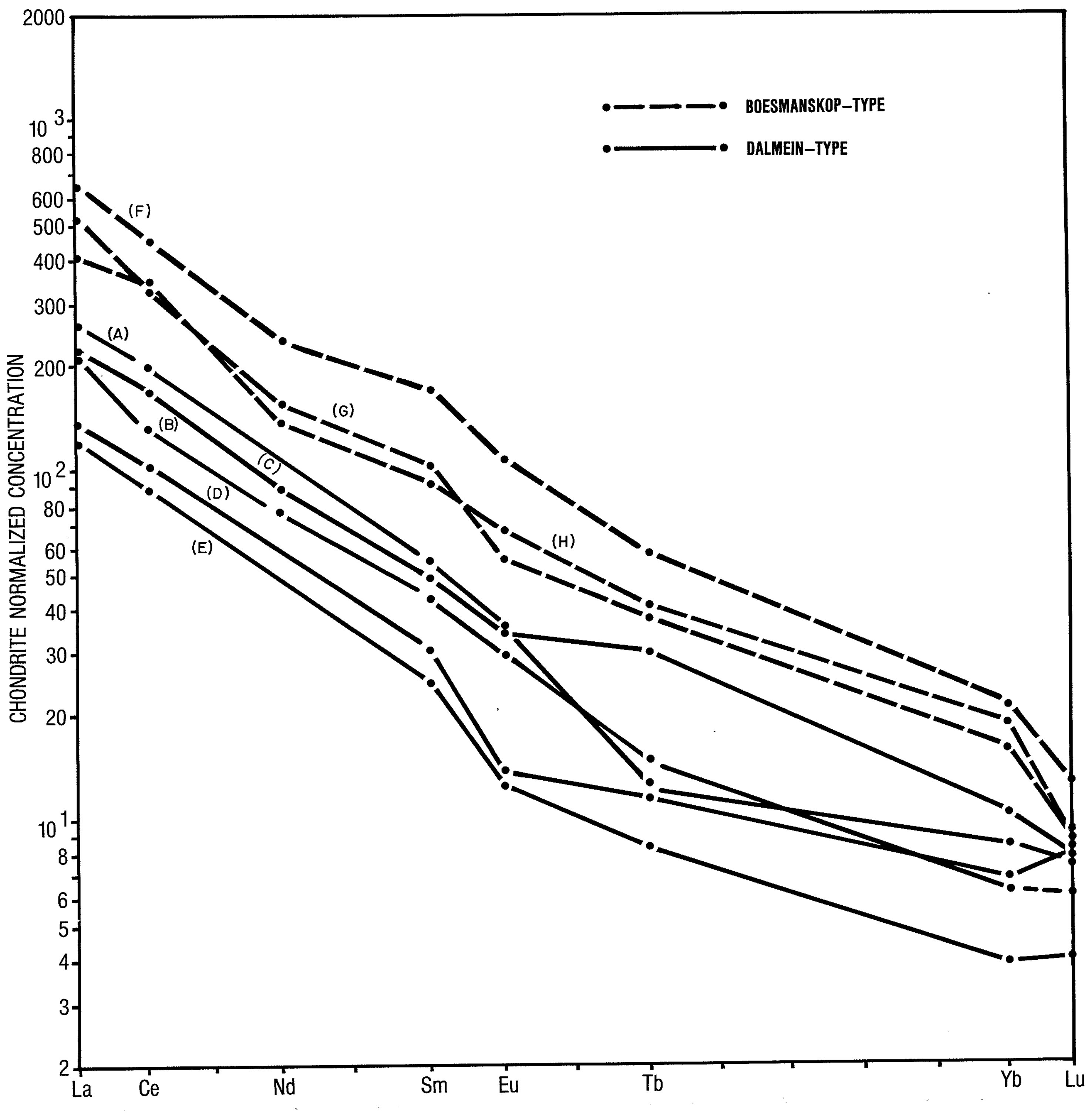

Figure 5 : Chondrite normalized REE plot for samples from the Dalmein- and Boesmanskop-type plutons. Data is from Table 1.

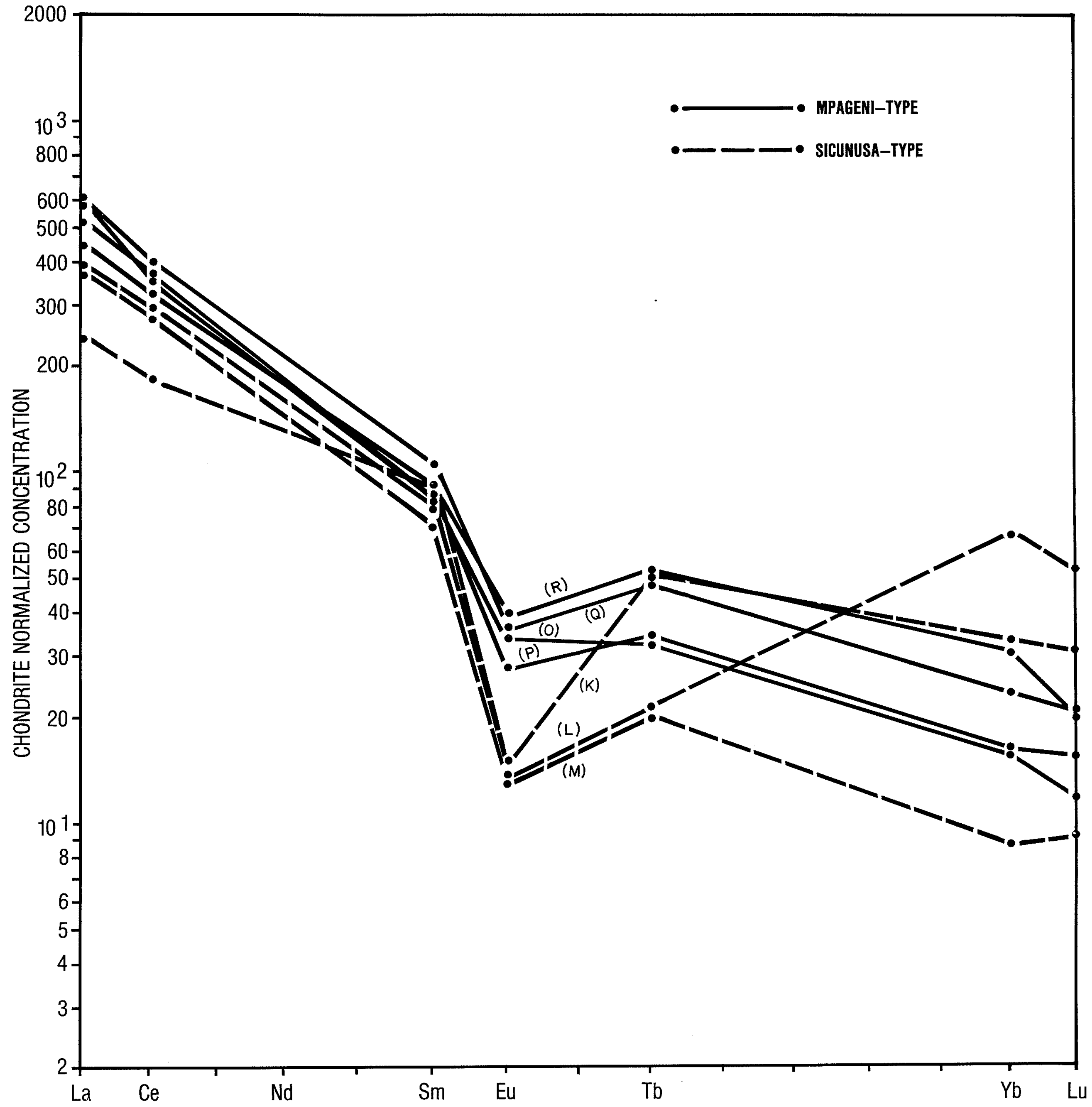

Figure 6 : *Chondrite normalized REE plot for samples from the Mpageni- and Sicunusa-type plutons. Data is from Table 1.*

The Mpageni- and Sicunusa-type plutons, although both granitic (*sensu stricto*) in composition, have significantly different REE traces (Fig. 6). The Mpageni-type plutons are significantly enriched in the light REE (La, 500-600 x over chondrites) and all have moderate negative Eu anomalies. The Sicunusa-type plutons are significantly less-enriched in the light REE and are characterized by pronounced negative Eu anomalies. In addition, the heavy REE in the Sicunusa-type plutons are variable such that the Eu_N/Lu_N ratio is unity or less. As a result these patterns are characteristically L-shaped in comparison to the more regular pattern of the Mpageni-type plutons.

V. ISOTOPIC DATA

A number of the late granite plutons have been isotopically dated using either Rb-Sr whole rock or U-Pb mineral techniques. A summary of the available data is presented in Table 3, where it is listed according to the five-fold subdivision described earlier.

All three of the Dalmein-type plutons have been dated, two of them by both available techniques. Collectively, these plutons represent the oldest of the five pluton sub-types with Rb-Sr ages ranging between ≅ 3,20-2,88 Ga and U-Pb ages between 3,17-3,28 Ga. In the case of the Dalmein pluton the Rb-Sr ages correspond with those obtained by U-Pb methods, whereas the Salisbury Kop pluton has lead ages which are significantly older than the Sr age. The Boesmanskop pluton, which is marginally younger than the Dalmein-type plutons in terms of both Rb-Sr and U-Pb ages, is characterized by a similar discrepancy between the two dating techniques. This feature can be explained in two possible ways (Barton, 1982); the first is that the older U-Pb mineral age reflects the emplacement age whereas the Rb-Sr date coincides with a later resetting event and, secondly, the older age reflects the source rock with the Rb-Sr age indicating the time of formation or emplacement. In the latter case this would suggest that the minerals (i.e. zircon and apatite) used in the U-Pb dating technique were incorporated as xenocrysts in the original granodioritic or syenitic magma.

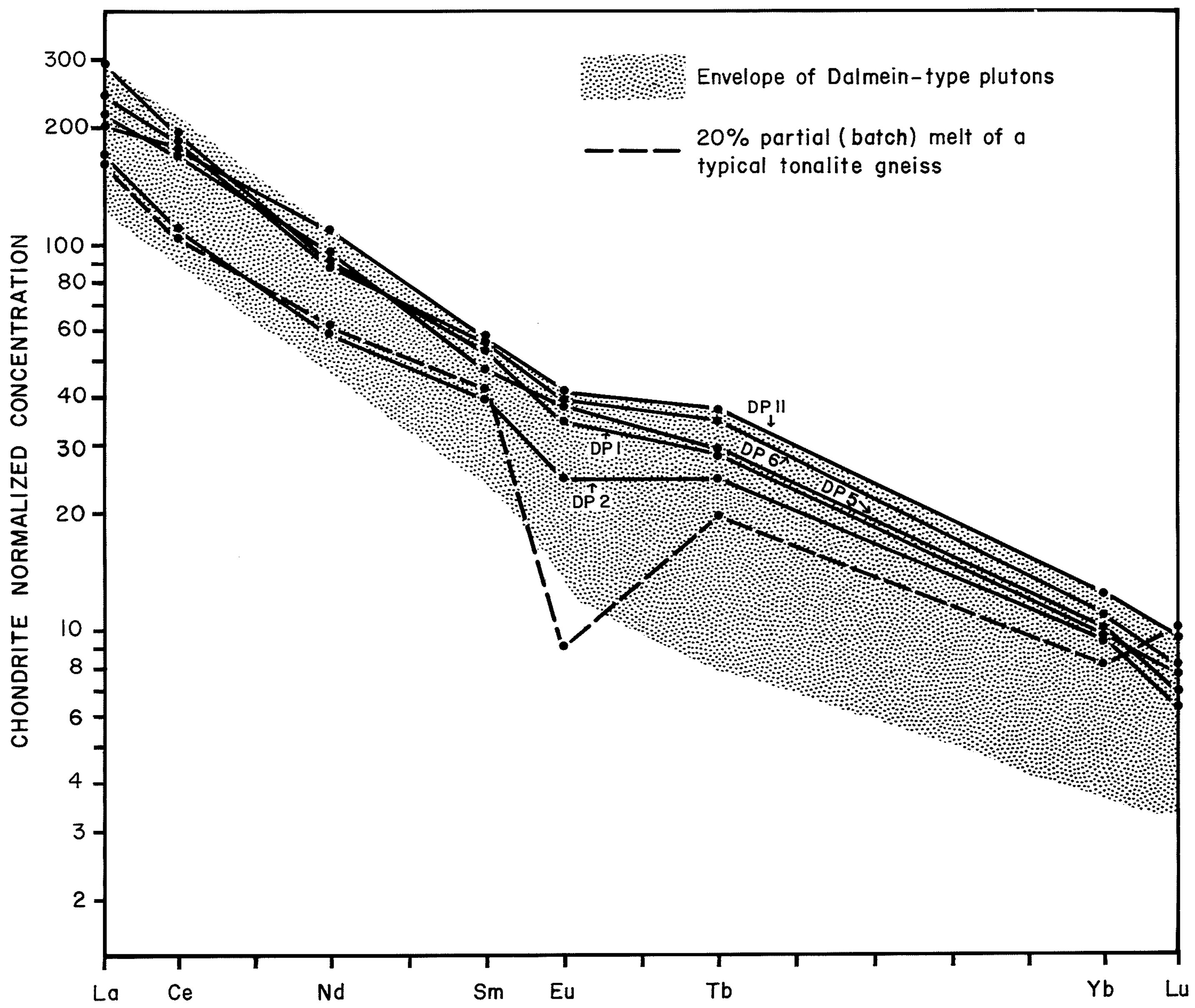

Figure 7 : *Chondrite normalized REE plot showing samples from the Dalmein pluton (data from Table 2) in relation to the envelope of Dalmein-type plutons from Fig. 5. Also shown is a model curve representing a 20% batch melt of a typical tonalite gneiss. Bulk partition coefficients and parental composition used in the calculation of the model curve are presented in the Appendix.*

The Cunning Moor tonalite pluton has yielded a Rb-Sr age of ≅ 2,78 Ga with an initial $^{87}Sr/^{86}Sr$ ratio of 0,7034 (Table 3). This age is significantly younger than the typical tonalite and trondhjemite gneisses occurring to the southwest of the Barberton greenstone belt and which are dated at between ≅ 3,5-3,0 Ga. It should be noted, however, that certain of these tonalite-trondhjemite gneisses are characterized by ages which are in fact comparable with that of the Cunning Moor pluton, but that these have been interpreted as possibly being reset ages (Barton *et al.*, in press). It is noteworthy that the Sesombi pluton in Zimbabwe, which was described earlier as being similar in many respects to the Cunning Moor pluton, is also characterized by a young (≅ 2,7 Ga) age (Table 3).

A distinction is apparent in the relative ages of the Sicunusa and Mpageni plutons, with the former yielding a Rb-Sr age of ≅ 2,61 Ga and the latter an age of approximately 2,5 Ga. Whether this age distinction applies to the two pluton sub-types as a whole is questionable, however, particularly in view of the geological age relationships that appear to exist between the Kwetta, and the Mooihoek and Mhlosheni plutons (see earlier). Additional isotopic work is clearly necessary in order to substantiate the five pluton sub-types in terms of both compositional and geochronological characteristics. It is noted too, that the Mpageni pluton, as in the case of the Boesmanskop and Salisbury Kop plutons, has an older U-Pb mineral age than the Rb-Sr age, a factor which raises further doubts as to a meaningful subdivision of the plutons in terms of the currently available isotopic data. In all likelihood, the emplacement of the later granite plutons occurred as a continuum of events spanning the period 3,2-2,5 Ga and although certain of the pluton sub-types were clearly emplaced before others, it appears unlikely that their formation was completely restricted to any one particular time inverval.

VI. PETROGENETIC ASPECTS

The late granite plutons in the Barberton Mountain Land and Swaziland are all characterized by a post-tectonic mode of emplacement which effectively terminated the development of the Archaean granitic crust in this region. As such, a major problem remaining in the complete understanding of crustal evolution in this area is that of the petrogenesis of this final magmatic cycle. Of particular importance is the fact that the localized and sporadic intrusion of the late granite plutons is a process which differs significantly from the large-scale magma pulses characterizing earlier developments of the Archaean crust. These plutons may, therefore, mark a change in the subsequent geological behaviour of the lithosphere — one which may be related to the widespread stabilization of cratonic terranes. The following section summarizes current thoughts on the petrogenesis of the late granite plutons, a topic about which very little has been written.

TABLE III

Isotopic Data
Late Post-Tectonic Granite (*Sensu Lato*) Plutons
in the Barberton Mountain Land and Swaziland

PLUTON		Rb-Sr (Whole Rock)		Initial $^{87}Sr/^{86}Sr$	U-Pb (Mineral)	
Dalmein pluton	1	3201 ± 43 Ma	*	0,7020 ± 0,006	3170 ± 190 Ma	ϕ
Salisbury Kop pluton	1	2927 ± 59 Ma	ϕ	0,7033 ± 0,0012	3280 ± 196 Ma	ϕ
Mliba pluton	1	2879 ± 88 Ma	+	0,7024 ± 0,0006	-	
Boesmanskop pluton	2	2848 ± 31 Ma	*	0,7040 ± 0,0014	3130 ± 188 Ma	ϕ
Cunning Moor pluton	3	2784 ± 53 Ma	x	0,7034 ± 0,003	-	
(Sesombi pluton)	3	(2690 ± 70 Ma	°	0,7008 ± 4)	-	
Sicunusa pluton	4	2608 ± 123 Ma	+	0,7006 ± 0,0188	-	
Mpageni pluton	5	2496 ± 76 Ma	§	0,7065 ± 0,0032	2810 ± 160 Ma	ϕ

Data from :
ϕ Oosthuyzen (1970)
\+ Davies (1971)
* J.M. Barton et al., (in press)
x E.S. Barton (in J.M. Barton et al., (in press)
° Hawkesworth et al. (1975)
§ de Gasparis (1967)

Condie and Hunter (1976) correctly viewed the Dalmein-type plutons as being older than either the Mpageni- or Sicunusa-type plutons. They were thus able to genetically interrelate the three pluton types by viewing the Dalmein-type magma as a parent to both the younger pluton categories. The Dalmein-type magma itself was regarded as having been derived by approximately 50% partial melting of a garnet-bearing granulite of intermediate (dioritic) bulk composition. This particular parental material was selected in preference to more typical tonalitic or trondhjemitic gneisses as Condie and Hunter (1976) presumably regarded the latter suite as being insufficiently enriched in the large-ion lithophile elements to adequately account for the production of Dalmein-type magma. However, this particular model was criticized by Jenner and Gorman (1977) who pointed out that Condie and Hunter's envisaged granulite parent had K, Rb and Ba contents that were anomalously high for a rock type considered to have undergone prograde granulite facies metamorphism.

In view of the criticism that the Condie and Hunter model has sustained, the above aspect is re-examined in terms of the relative REE abundances in typical Archaean tonalite gneisses and the Dalmein-type plutons. It is the writer's conviction that tonalite or trondhjemite gneisses constitute the most logical source for the Dalmein-type magma in terms of their abundance in the region. Furthermore, the probable existence of high Archaean geothermal gradients obviates the need to call upon granulite facies conditions before partial melting occurs. In Fig. 7 REE data for the Dalmein pluton, as well as the envelope encompassing all Dalmein-type plutons, are compared with a model curve that was derived by 20% partial (batch) melting of a typical Archaean tonalitic gneiss. It is evident that the model REE abundances are not unlike the observed values except that the model trend has a larger negative Eu anomaly than the actual trends. However, this feature is purely a function of the high partition coefficient used for Eu into plagioclase (see Appendix), a value which is, in fact, strongly dependent on the magmatic oxygen fugacity (Sun *et al.*, 1974). In the absence of data pertaining to this variable it is feasible that fO_2 may have been higher than that reflected in the partition coefficient used and that the melt was not, therefore, as depleted in Eu as indicated. Despite the Eu anomaly, the model distribution of REE between a typical tonalitic precursor and a Dalmein-type melt fraction is grossly compatible with the observed data.

Assuming the derivation of a Dalmein-type magma, Condie and Hunter (1976) related both the Mpageni- and Sicunusa-type plutons to this parent by processes of fractional crystallization. The main differences between the two pluton types are the lower Sr contents and the more significant negative Eu anomalies in the Sicunusa-types. Other differences include higher Ba contents and generally lower SiO_2 abundances in the Mpageni-type plutons. These variations can be suitably accommodated by fractionating slightly differing mineral assemblages from a compositionally similar magma which varies only in terms of its oxygen fugacity. Thus, the Mpageni-type magmas are considered to have been derived by fractionating the assemblage plagioclase + quartz + biotite in the ratio 45:45:10, whilst the Sicunusa-types represent differentiates from a crystallizing assemblage of plagio-clase + quartz + biotite + K-feldspar in the ratio 57:27:8:8 . The presence of liquidus K-feldspar in the latter case accounts for the lower Ba contents in the Sicunusa differentiates, whereas the crystallization of less plagioclase during the differentiation of the Mpageni magmas contributes, in part, to their higher Sr contents. Condie and Hunter (1976) also envisaged a lower oxygen fugacity in magmas fractionating to form the Sicunusa-type plutons than in those forming the Mpageni-type plutons (i.e. $\cong 10^{-9}$ atm as compared to $\cong 10^{-8}$ atm). This would have the effect of increasing the partition coefficient of Eu into plagioclase in the former case such that the differentiated magmas could be characterized by proportionately larger negative Eu anomalies. A possible weak-ness of this model is that the partition coefficient of Sr into plagioclase, unlike that of Eu, is not dependent on the oxygen fugacity conditions (Sun *et al.*, 1974). Thus, whereas lower Eu contents in the Sicunusa-type plutons are deemed to be a function of fO_2, concomitantly lower Sr values in these bodies cannot likewise be related to the same parameter. Clearly, a more detailed evaluation of the trace element characteristics of these pluton sub-types is necessary.

No petrogenetic studies have yet been undertaken on the Cunning Moor-type plutons and it is not certain, therefore, whether their derivation can be accommodated into a scheme whereby the various pluton sub-types are genetically inter-related. The modelling of Condie and Hunter (1976) does, however, suggest the possibility of a relationship between the formation of the Mpageni-type plutons and the Cunning Moor tonalite. It was suggested that the former represented differentiated magmas arising from the fractionation of a plagioclase + quartz + biotite assemblage crystallizing from a Dalmein-type magma. Condie and Hunter (1976) made no mention of the existence of these fractionates which conceivably would be preserved at deeper crustal levels than the rising Mpageni-type magmas. In view of the fact that the Cunning Moor tonalite is exposed on a topographically low-lying, deeply eroded surface it is possible that this body represents these fractionates. This notion could best be confirmed by the presence of a positive Eu anomaly but, in the absence of REE data for this body, must remain speculative. An alternative to this scheme would be to genetically divorce the Cunning Moor-type plutons from the processes which relate the Dalmein-, Mpageni- and Sicunusa-type plutons, and to consider the former as a partial melt derivative of an older tonalite-trondhjemite gneiss precursor. This suggestion, too, must await more detailed petrogenetic considerations of this pluton-type.

The Boesmanskop syeno-granite complex is the one suite whose origin is difficult to reconcile with any of the processes mentioned above. This complex is characterized by high Rb, Sr, Ba and total REE contents and yet was fractionated from a magma which must have been inherently SiO_2 depleted in order to form a rock suite dominated by syenites and quartz-syenites. The high incompatible element contents suggest a derivation of the parent magma either by extreme differentiation or small degrees of partial melting. Detailed studies on the Boesmanskop complex indicate that both crystal and liquid fractionation processes caused the observed compositional ranges in this suite (Anhaeusser *et al.*, 1979, and in press). Furthermore, the nature of the source material from which the Boesmanskop magma was derived is a question which cannot be unequivocally resolved. Arth and Hanson (1975) suggested that the Archaean Linden syenite body in Minnesota, which has similar chemical characteristics to the Boesmanskop syenite pluton, was derived by very small degrees (≅ 1%) of partial melting of a mixed peridotite-eclogite source. Glikson (1976) pointed out that a similar origin cannot be reconciled with certain of the trace element characteristics of the Boesmanskop complex, a viewpoint which is also substantiated by the probably unrealistic nature of a 1% partial melt in terms of this body. As a result, Anhaeusser *et al.* (in press) have preferred consideration of a more felsic source in which the large-ion lithophile elements are undoubtedly more abundant than in the source envisaged by Arth and Hanson (1975). Partial melting of this material would necessarily have taken place at high confining or water pressures where the granite eutectic coincides with relatively silica-depleted compositions (Luth *et al.*, 1964; Huang and Wyllie, 1973). In the event of either a peridotite-eclogite or a more felsic source, the derivation of the Boesmanskop magma appears to have had a deep-seated origin, a feature which distinguishes it from the other late granite plutons.

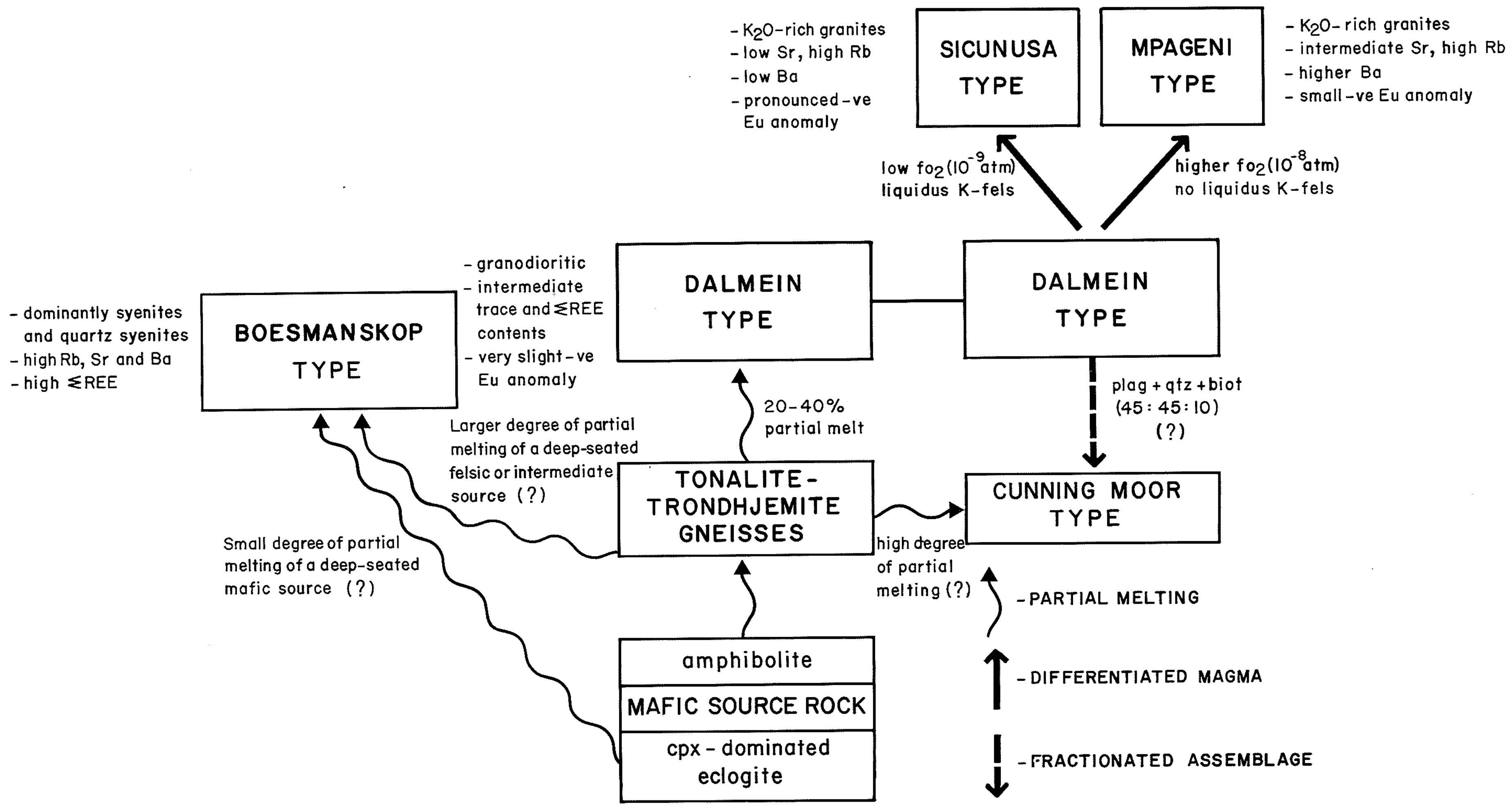

Figure 8 : Simplified scheme summarizing the genetic interrelationships between the late granite plutons and other major rock units in the Barberton-Swaziland granite-greenstone terrane.

A summary of current ideas pertaining to the petrogenesis of late granite plutons in the Barberton area and Swaziland is presented in Fig. 8. This petrogenetic scheme tends to relate the origin of the plutons to crystal-liquid fractionation processes enacted upon existing rocks in the region and, for the most part, exotic parental material has not had to be resorted to. In Fig. 8, the Dalmein-type magmas are related to tonalite-trondhjemite gneiss precursors which, themselves, are regarded as having been derived from amphibolites (metabasalts) probably originating from adjacent greenstone successions (Robb and Anhaeusser, in press). The Dalmein magmas are regarded, in this paper, as having been derived by 20-40% partial melting of the tonalite-trondhjemite parent. Dalmein-type magmas are also viewed as possibly representing the parental liquid to the Mpageni-, Sicunusa- and Cunning Moor-type plutons. Mpageni and Sicunusa magmas are regarded as differentiates of this parental liquid with differences in the two pluton-types being attributed to varying liquidus assemblages and fO_2 conditions (Condie and Hunter, 1976). The origin of the Cunning Moor tonalite pluton is speculative at this stage but could reasonably be related to the fractionating assemblage (i.e. predominantly plagioclase + quartz + biotite) crystallizing from the Dalmein-type parental magma. Alternatively, this pluton could also be related to a fairly high degree (> 50%) of partial melting of a tonalite-trondhjemite gneiss precursor. Finally, the origin of the Boesmanskop syeno-granite complex is related either to a very small degree of melting of a deep-seated mafic source or to a more realistic melt proportion derived from a deep-seated felsic or intermediate source. In the former case it is possible that the mafic source was derived by progressive burial of a greenstone belt-derived (komatiitic) amphibolite which inverted to a clinopyroxene-dominated eclogite (Robb and Anhaeusser, in press; Robb, 1981). It is a noteworthy feature of residual clinopyroxenes that they contain more SiO_2 than residual hornblendes (Helz, 1973) and that melts equilibrating with the former will be silica-deficient by comparison with melts formed in equilibrium with the latter.

The above scheme represents an attempt to collate and process the presently available information on late granite plutons in the Barberton region and Swaziland. Although based on only a limited amount of geological and geochemical data, this framework nevertheless provides an indication of the role which this magmatic cycle has played in Archaean crustal evolution.

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APPENDIX - PARTIAL MELT MODEL FOR THE DERIVATION OF A DALMEIN-TYPE MAGMA FROM A TONALITIC PARENT

	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
Bulk partition coefficients - melt phase (*)	0,12	0,14	0,09	0,06	1,21	0,03	0,06	0,02
Bulk partition coefficients - parent	0,25	0,25	0,16	0,08	2,00	0,05	0,04	0,04
Parental composition (ppm) (+)	15	24	9	1,7	0,7	0,18	0,30	0,06

(*) - Bulk partition coefficients calculated using mineral/melt distribution coefficients compiled in Robb (1981).

(+) - Parental composition represents a typical trondhjemite gneiss compiled from data in Robb (1981).

Using the batch melt equations of Shaw (1970), the composition of a 20% partial melt of the above parent is as follows :

	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu
ppm	39,9	64,5	27,1	6,34	0,51	0,74	1,32	0,25

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