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DETAILED STUDIES OF SELECT MIGMATITE OUTCROPS IN THE REGION SOUTHWEST OF THE BARBERTON GREENSTONE BELT AND THEIR SIGNIFICANCE CONCERNING THE NATURE OF THE EARLY ARCHAEAN CRUST IN THE REGION

by

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ABSTRACT

Detailed studies of migmatites in the region southwest of the Barberton greenstone belt have been carried out in the hope that they may elucidate the primary relationships between early granitic *(sensu lato)* and greenstone crust in the area. Certain migmatites are formed by the intrusion of tonalitic/trondhjemitic magma into segments of pre-existing greenstone (ensimatic) crust; in others, the mafic component of the migmatite is intrusive into well-foliated tonalite or trondhjemite gneisses; a third type is characterized by anatectites intrusive into both gneiss and greenstone components.

Detailed mapping of migmatite outcrops has shown that the tonalite and trondhjemite gneiss plutons are characterized by discrete, episodic emplacement. Where recognized, the older trondhjemite gneiss phases have an unequivocal relationship with respect to the greenstones; the younger tonalite/trondhjemite gneiss plutons, however, are clearly intrusive into both greenstones and older gneiss phases.

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I. INTRODUCTION

Ever since the pioneering work of Sederholm was responsible for the selective description of migmatites and the recognition of their role in granite petrogenesis, these "mixed rocks" have been the object of innumerable studies. In recent times migmatites are recognized as having been formed by *in situ* anatexis (von Platen, 1965; Ashworth, 1976), by subsolidus metamorphic differentiation (White, 1966; Misch, 1968; Hedge, 1972; Amit and Eyal, 1976; Yardley, 1978), by metasomatism (King, 1965; Viljoen and Viljoen, 1969a) and by the physical emplacement of an externally derived magma (Lowman, 1965; Van Schmus and Anderson, 1977). Workers in highly deformed areas have also demonstrated the relationship existing between intensity of deformation and genesis of migmatites (Mackenzie, 1957; Myers, 1977).

Inasmuch as Archaean terranes the world over are characterized by a controversy concerning the nature and development of the primordial crust, it was decided to examine migmatites in the Barberton region, in the hope that their characteristics might shed light on this problem. The well-exposed terrane to the southwest of the Barberton greenstone belt (Figure 1) was selected for this purpose as the regional mapping here is virtually complete (Anhaeusser and Robb, 1978; Anhaeusser, 1980). The results of detailed mapping (1:50) undertaken in this area have led to the recognition of three types of migmatite. This paper provides a description of these types and attempts to explain their formation in terms of the regional geology of the Barberton Mountain Land. A description of new features only recently observed, provides information that has led to a better understanding of the nature and development of the early Archaean crust in the area.

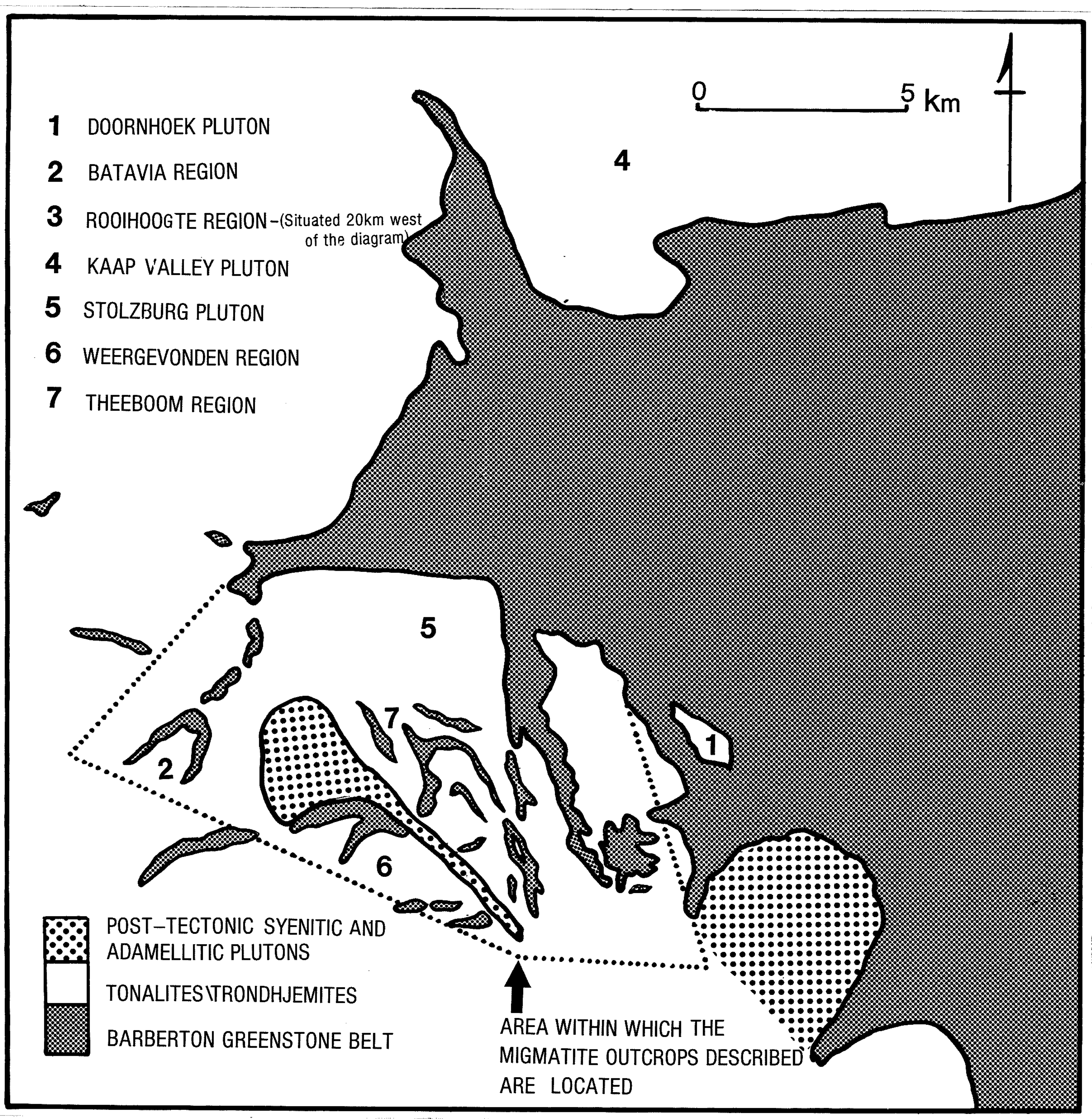

Figure 1 : Map of the southwestern portion of the Barberton greenstone belt showing the region in which the migmatites described in the text are located. Also shown are the localities of some of the discrete tonalite/trondhjemite plutons or "cells" referred to.

II. MIGMATITE DESCRIPTION

A number of migmatite outcrops were mapped as part of this study, all but one of which occur in the region outlined in Figure 1. The pertinent characteristics of a representative selection of these migmatites are presented in schematic form in Figure 2. The seven diagrams (A-G) presented in this figure all depict portions of individual, geographically discrete, migmatitic outcrops and their approximate localities are described in the captions to Figure 2.

The migmatites described in this paper are all related to the oldest suite of granites *(sensu lato)* in the area (Barton, 1980) and differ from the migmatites related to younger granitoids, the latter having been described elsewhere (Anhaeusser and Robb, 1980). As a result the migmatites in the study region can be interpreted in two ways; firstly, in terms of their often complex style of deformation they could represent a sialic basement upon which the Barberton greenstone belt was deposited, or secondly, they may have formed in response to the physical interaction between pre-existing greenstones and marginally younger, or coeval (according to isotopic data; Barton, 1980) tonalitic and trondhjemitic gneisses. Regional mapping in the area, however, points to the fact that the development of migmatites is not randomly distributed and that the latter are invariably situated in close proximity to the numerous greenstone xenoliths found in the region (Anhaeusser and Robb, 1978). This suggests, albeit superficially, that the migmatites are more likely to represent the second of the above possibilities.

The detailed mapping of migmatite outcrops indicates that three types of migmatite can be described :

(a) Type 1, where tonalitic or trondhjemitic gneisses are clearly intrusive into mafic (and felsic) units which are correlatable with recognized greenstone lithologies (Figure 2A and D);

(b) Type 2, where both gneiss and greenstone components are present in addition to, often significant, proportions of anatectic material that has intruded all pre-existing components thereby obscuring the primary relationships between them (Figure 2B and C); and

(c) Type 3, where the mafic component of the migmatite is intrusive into well-foliated tonalite or trondhjemite gneisses (Figure 2E and G).

In terms of this subdivision Type 1 and Type 3 migmatites represent opposite extremes, as the former has tonalitic or trondhjemitic gneiss that is younger than mafic xenoliths that can often be correlated with greenstone lithologies, whereas the latter consists of gneisses that are intruded by mafic dykes not directly correlatable with the greenstones. Type 2 migmatites may represent either extreme but invariably contain a significant anatectic component that obscures all primary relationships.

Migmatites of Type 1 are formed by the intrusion of tonalite/trondhjemite gneiss into pre-existing greenstone lithologies of variable composition. For example, as illustrated in Figure 2A and Plate 1A, a tonalitic gneiss intrudes a heterogeneous (migmatized) felsic meta-tuff. The felsic meta-tuff has been extensively recrystallized as well as now containing innumerable anatectic veinlets. Where unaffected by these veinlets this unit appears to have retained its original chemistry (sample A2, Table 1) which is markedly similar in both major and trace elements to that of unaltered acid tuffs in a large nearby greenstone xenolith (Anhaeusser and Robb, 1978). In places the felsic meta-tuff has been tightly folded and it is here that the maximum development of anatectic veinlets occurs (Figure 2A). The anatectic material has apparently migrated preferentially from fold limbs to fold hinge zones over a relatively small area. This outcrop, therefore, demonstrates a small-scale example of where the extent of *in situ* migmatization in metamorphic rocks is closely related to both style of deformation and magnitude of strain (Mackenzie, 1957).

In Figure 2D an amphibolitic meta-basalt is intruded by a well-foliated trondhjemite gneiss. Both units have been deformed together by stresses from at least two directions so that a superimposed fold pattern prevails (i.e. small dome and basin-like features occur). Many of the mafic xenoliths in this category have been extensively assimilated by the intrusive tonalites or trondhjemites. Despite the deformation and assimilation, clearly cross-cutting and intrusive relationships are preserved, and these serve to characterize the Type 1 migmatites.

Type 2 migmatites characteristically contain anatectites that intrude both pre-existing amphibolitic and gneissic components. Figure 2B illustrates an amphibolitic meta-basalt of komatiitic composition that has been intruded and fragmented by a felsic anatectite. In this case it is the anatectite that is responsible for migmatization (i.e. the formation of agmatite) and the relationship between trondhjemite gneiss and amphibolite is not preserved. Figure 2C illustrates a broad contact zone between well-foliated banded trondhjemite gneiss and amphibolitic meta-basalt, again of komatiitic composition. The contact zone is represented by the same amphibolite intruded by a series of felsic anatectites arranged in a systematic lit-par-lit array (Plate 1B). Again, the primary relationship between gneiss and amphibolite is obscured and it is the interaction of anatectite and amphibolite that is responsible for the development of a migmatite.

Typical Type 3 migmatites are shown in Figure 2E and G where amphibolitic dykes of tholeiitic composition intrude well-foliated tonalitic or trondhjemitic gneisses. These dykes have, at least, been involved in the later stages of dynamo-thermal metamorphism that affected the region and have been deformed and migmatized so that, in some instances, they can appear similar to mafic xenoliths described from Type 1 migmatites (Plate 1C). As a result their recognition is dependent on the presence of a clearly discordant relationship between them and pre-existing trondhjemite/tonalite gneisses. Where intense structural deformation has been responsible for the concordance of many linear mafic bodies with respect to enveloping gneisses, the identification of possible dykes becomes equivocal and, hence, they are not widely recognized in the region.

Many of the migmatite outcrops encountered cannot be assigned a definite interpretation principally because of the effects of deformation. In Figure 2C, for example, the foliation in a boudinaged lens of trondhjemite gneiss is truncated by amphibolite in a number of places. If the orientation of maximum principal strain during deformation were slightly oblique to the contact plane of the two units, the truncation could be due to the rotation of boudinaged units (i.e. lozenge-shaped boudins; Rast, 1956; Charlesworth and Evans, 1962).

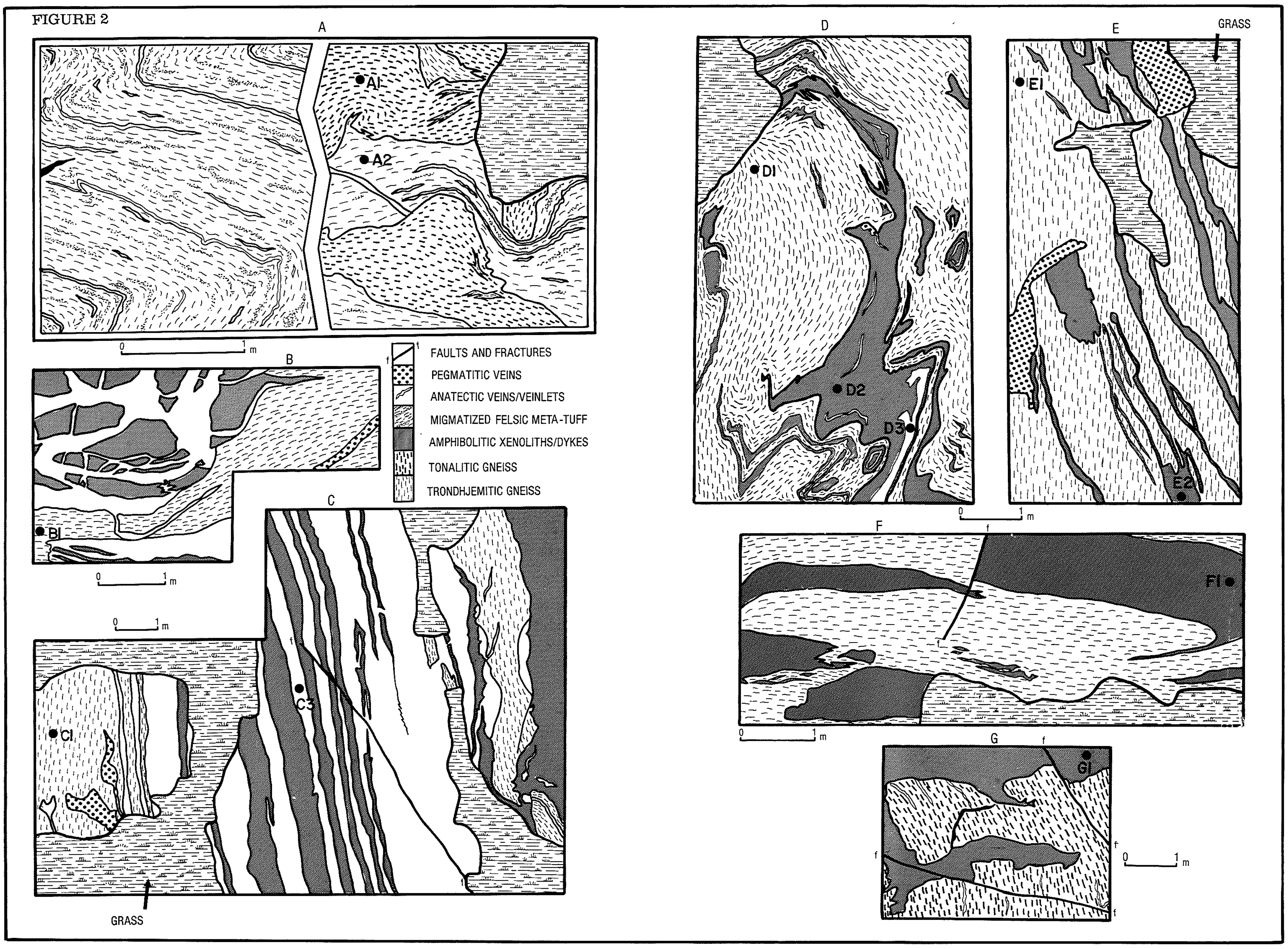

Figure 2 : A : *Exploded diagram illustrating the intrusion of tonalitic gneiss into a heterogeneous (migmatized) felsic meta-tuff in the Weergevonden region. A1, A2 etc. are the localities of analysed samples presented in Table 1.*

B : *Fragmentation of amphibolite by anatectite in the Rooihoogte region.*

C : *Contact zone between trondhjemite gneiss (partly covered by grass on the left of the diagram) and amphibolite where a lit-par-lit array of anatectic veins have intruded both the trondhjemite and amphibolite. On the right of the diagram the foliation in a boudinaged lens of trondhjemite gneiss is clearly discordant with respect to the amphibolite with which it is juxtaposed; from the Theeboom region.*

D : *Deformed xenolith of amphibolite within well-foliated trondhjemite gneiss in the Batavia region.*

E : *Dykes of amphibolite intruding well-foliated trondhjemite gneiss in the Batavia region.*

F : *Linear dyke-like bodies of amphibolite within trondhjemite gneiss from an area east of the Weergevonden region.*

G : *Deformed amphibolitic dyke intrusive into tonalitic gneiss from the Batavia region.*

On the other hand, a close examination of the amphibolite-banded trondhjemite gneiss contact shows that the leucocratic banding in the gneisses is also truncated by the amphibolite (Plate 1E). This could be construed as evidence for the intrusion of gneiss by amphibolite in spite of the stretching and concordancy that has generally been applied to the outcrop. For example, Dearnley and Dunning (1968) have, in some instances, used only short lengths of discordant contact when identifying the highly deformed dykes of the Lewisian in Scotland.

In Figure 2F, dominantly linear bodies of amphibolite of tholeiitic composition are enveloped by well-foliated trondhjemite gneiss such that mutual contacts are generally concordant. The amphibolite has been slightly assimilated by felsic material and could possibly represent xenoliths within the gneiss. However, in view of the assimilated nature of the dykes described above and judging by the dyke-like "horned" structure shown in Figure 2F as well as the occasional small lengths of discordant contact between gneissic schlieren and amphibolite demonstrated in Plate 1D, it is equally likely that the amphibolites here may be intrusives. This interpretation is equivocal, however, as this migmatite outcrop is located in an area where no other dykes of this nature have been recognized and where extensions of the dominantly tholeiitic upper portions of the Onverwacht Group in the Barberton greenstone belt were previously considered to have been intruded and migmatized by younger trondhjemitic gneiss.

The brief descriptions presented above indicate that a variety of processes have been responsible for the development of the migmatites in the study area. On the one hand tonalitic/trondhjemitic gneisses have intruded and migmatized portions of recognizable greenstone (ensimatic) crust; on the other hand a suite of now deformed and migmatized mafic dykes have intruded tonalitic/trondhjemitic (sialic) crust. In all cases the rocks involved have been deformed, often to the extent where the primary relationships between migmatite components are obscured. The remainder of the paper discusses in more detail some of the characteristics of the three dominant phases of the migmatites, namely the tonalitic/trondhjemitic gneisses, the anatectites and the amphibolites.

III. TONALITE AND TRONDHJEMITE GNEISSES

In the past the numerous tonalite and trondhjemite gneiss plutons that diapirically intrude the Barberton greenstone belt were largely considered to be cogenetic as well as broadly coeval (Viljoen and Viljoen, 1969a; Oosthuyzen, 1970). Recent work in the Barberton Mountain Land has, however, shown that this suite of rocks varies considerably in age between ≅ 2,9 b.y. and ≅ 3,45 b.y. (Barton, 1980). In addition, geological mapping has revealed the presence of discrete older and younger trondhjemitic gneisses where the latter clearly intrude the former (Anhaeusser and Robb, 1978). This relationship can be demonstrated in another section of the outcrop depicted in Figure 2C. The banded trondhjemite gneiss, a boudinaged lens of which is seen directly juxtaposed with the amphibolitic unit in Figure 2C, is intruded by a younger trondhjemite gneiss at some distance away from the amphibolite. The younger gneissic unit, illustrated in Figure 3, does not contain the leucocratic banding characteristic of the older unit and transects both the banding and foliation in the latter. Both units have similar major element chemistries but are characterized by different Sr contents (Anhaeusser and Robb, 1978; Table 1, Columns 4 and 5, and Figure 4). The relationships seen at this outcrop indicate that the younger, and volumetrically dominant, gneiss unit must intrude and, therefore, contain xenoliths of, combined older gneiss

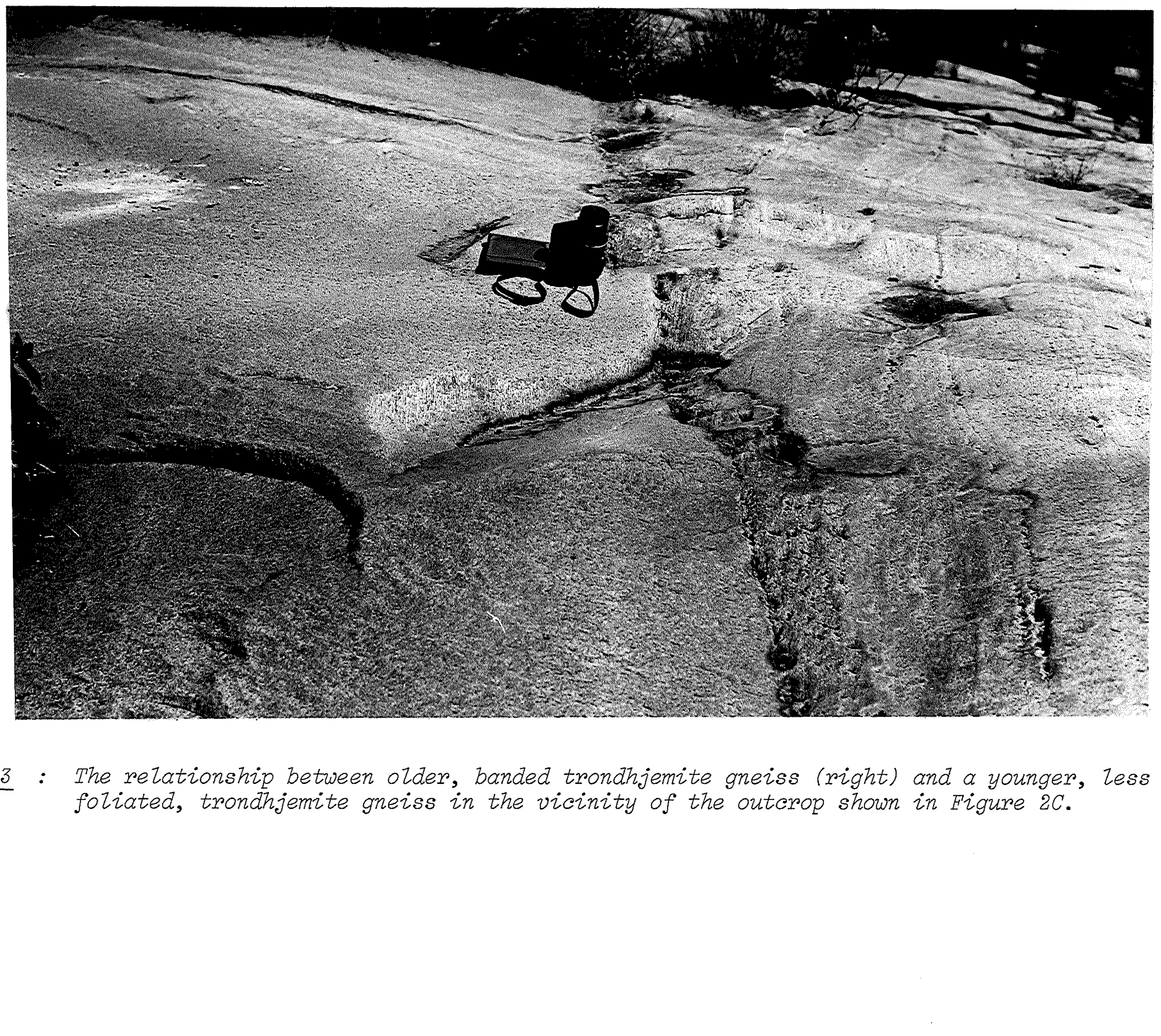

Figure 3 : *The relationship between older, banded trondhjemite gneiss (right) and a younger, less well-foliated, trondhjemite gneiss in the vicinity of the outcrop shown in Figure 2C.*

and amphibolite. In terms of the regional geology, younger, and volumetrically dominant, tonalite/trondhjemite gneiss plutons similarly intrude and deform the pre-existing greenstones (Figure 2A and D); they also, however, intrude any older sialic crust, whose relationships with respect to the greenstones may be equivocal principally because of the deformation subjected to both units. The development of migmatites usually takes place along the margins of homogeneous tonalitic/trondhjemitic plutons and it is these places, therefore, that are most likely to preserve primary relationships between the greenstones and remnants of sialic crust that may, or may not, have pre-dated them.

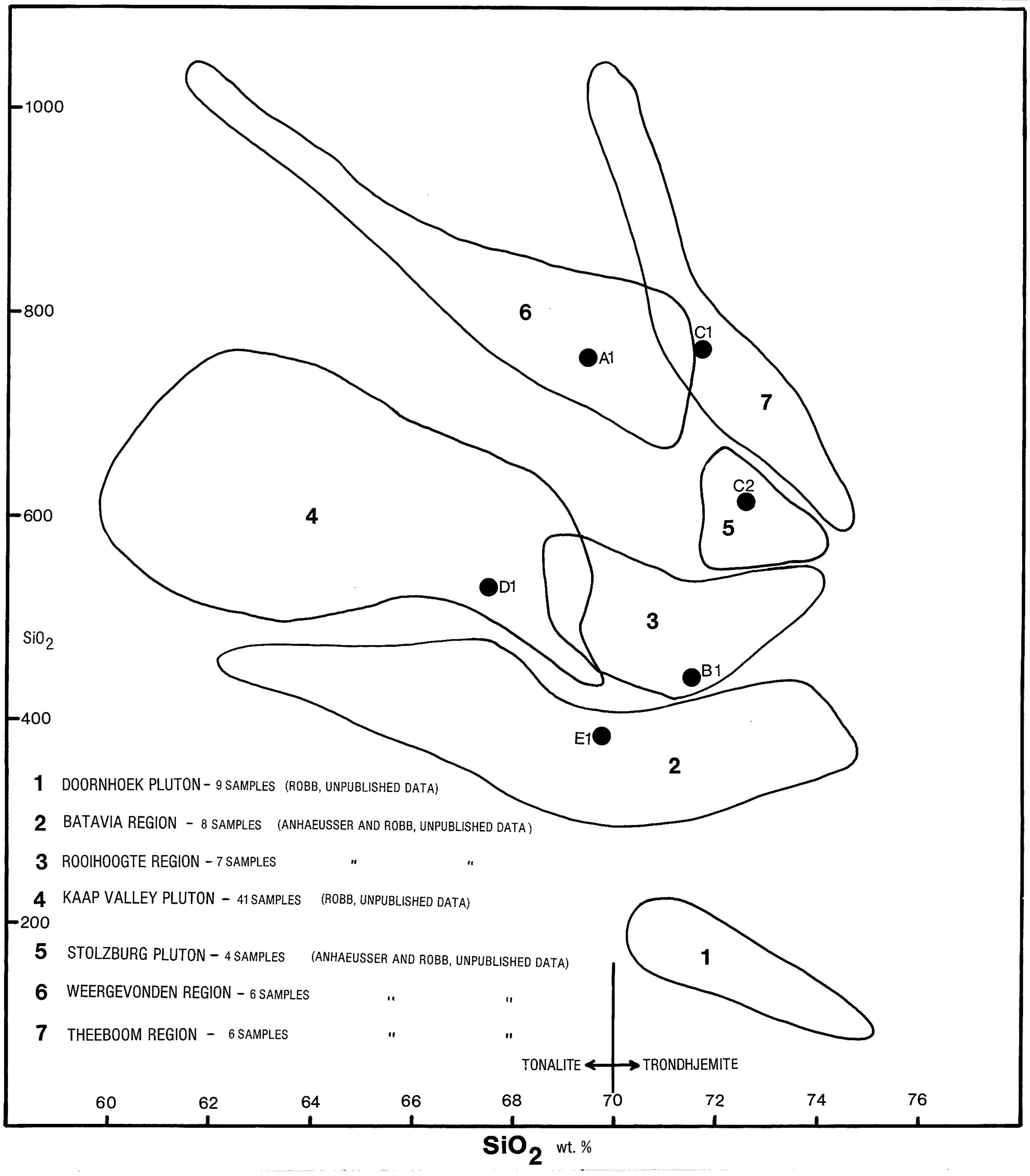

Figure 4 : *Plot of SiO_2 v Sr for tonalitic and trondhjemitic gneisses from the region southwest of the Barberton greenstone belt. Individual samples plotted are from Table 1.*

A major problem in recognizing the episodic emplacement of tonalitic/trondhjemitic plutons is the similarity in their major element chemistry and the fact that outcrops such as that shown in Figure 3 are rare. Data at the author's disposal does suggest, however, that Sr may be used in "fingerprinting" geographically discrete tonalite/trondhjemite plutons or "cells", some of which are shown in Figure 1. In Figure 4 a plot of SiO_2 v Sr illustrates the fact that certain plutons may be wholly trondhjemitic (where a trondhjemite is described as a leucotonalite and is defined here as having $SiO_2 > 70\%$; e.g. the Doornhoek Pluton), others may be wholly tonalitic ($SiO_2 < 70\%$; e.g. Kaap Valley Pluton) whereas most are characterized by both tonalitic and trondhjemitic compositions. However, each of the plutons, or geographically discrete cells, are characterized by a distinctive Sr content that varies between 100 and 1 000 ppm. Although the available data indicates that each pluton or cell has a distinctive Sr content it is obvious that, as more information is added, overlaps will occur and only low-, intermediate- and high-Sr plutons will be recognized.

The SiO_2 v Sr diagram is significant in terms of the description of migmatites because it demonstrates that the tonalite or trondhjemite component in the migmatites is generally similar in composition (particularly

CHEMICAL ANALYSES OF SELECT SAMPLES FROM THE MIGMATITE OUTCROPS DESCRIBED IN FIGURE 2

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		A1	A2	B1	C1	C2	C3	C4	D1	D2	D3	E1	E2	F1	G1
Wt.%	SiO_2	68,77	73,47	71,70	71,50	71,54	73,43	50,54	67,61	48,95	75,21	69,85	49,13	51,80	50,26
	TiO_2	0,52	0,20	0,20	0,15	0,38	0,12	0,73	0,30	1,22	0,03	0,31	0,88	1,25	1,13
	Al_2O_3	17,18	13,05	15,62	15,60	16,48	14,96	9,40	17,86	14,97	13,52	15,56	16,60	13,66	12,10
	Fe_2O_3	3,22	2,18	2,19	1,30	2,43	0,88	13,47	3,08	11,40	0,76	3,23	10,31	15,76	11,62
	MnO	0,01	0,02	0,01	0,01	0,01	0,01	0,46	0,06	0,17	0,01	0,01	0,14	0,23	0,09
	MgO	1,14	0,90	0,85	0,40	1,04	0,44	10,47	1,20	6,14	0,22	1,23	8,10	4,00	11,40
	CaO	3,09	0,77	3,05	1,79	2,55	1,12	11,52	4,35	11,49	1,94	2,93	9,70	6,72	9,10
	Na_2O	4,45	3,57	4,29	5,90	4,26	4,59	1,75	4,69	3,33	5,53	4,08	3,14	2,30	3,71
	K_2O	1,51	4,61	0,91	2,12	1,92	4,10	0,79	0,99	0,58	0,72	1,22	1,46	1,38	0,66
	P_2O_5	0,18	0,07	0,06	0,04	0,15	0,07	0,01	0,09	0,08	0,01	0,07	0,42	0,13	0,06
	L.O.I.	0,85	0,48	0,63	0,42	0,36	0,60	1,02	0,48	0,53	0,54	0,75	0,97	1,53	0,65
	TOTALS	100,91	99,32	99,51	99,23	101,11	100,32	100,15	100,74	98,86	98,49	99,24	100,85	99,30	100,78
ppm	Rb	58	76	14	46	60	97	14	17	5	12	18	64	30	49
	Sr	754	122	434	604	810	339	184	549	148	231	386	434	100	190
	Ba	220	993	120	620	584	655	81	159	10	82	237	228	248	34

Columns 1, 3, 4, 5, 8, 11 - Tonalite/Trondhjemite gneisses
Columns 7, and 9 - Komatiitic and tholeiitic xenoliths
Column 2 - Felsic meta-tuffaceous xenolith
Columns 12, 13 and 14 - Tholeiitic dykes
Columns 6 and 10 - Anatectites

(i) Samples all analysed by X-ray fluorescence in the Department of Geology, University of the Witwatersrand, by L.J. Robb.

(ii) Sample localities from Figure 2 except C2 and C4 which come from nearby the outcrop shown in Figure 2C.

(iii) Total iron as Fe_2O_3.

its Sr content) to that of the trondhjemite pluton or cell with which it is associated. For example, samples A, B1, C1 and E1 (from Table 1 and which correspond to the migmatite outcrops in Figure 2A, B, C and E respectively) all have compositions which correspond to the plutons or cells with which they are associated, namely the Weergevonden cell, the Rooihoogte cell, the Theeboom cell and the Batavia cell (Figure 1). The older trondhjemite gneiss (C1), which occurs as a xenolith together with the amphibolite unit in the younger gneiss (C) in the outcrop shown in Figure 2C, has a different composition to the latter (i.e. lower Sr) and falls in the compositional field of the Stolzburg Pluton. The tonalite gneiss (D1 -Table 1 and Figure 2D) comes from a migmatite outcrop associated with the Batavia cell and is seen to have a composition very close to it in Figure 4. It is apparent, therefore, that the tonalite/trondhjemite plutons are, themselves, intimately associated with the process of migmatization such that the development, at least of Type 1 and Type 2 migmatites, is genetically related to the emplacement of these bodies.

IV. ANATECTITES

All the migmatite outcrops mapped show evidence of having undergone varying degrees of anatexis during their formation. In particular, Type 2 migmatites (Figure 2B and C) are characterized by intrusion, into both trondhjemitic and amphibolitic components, of significant proportions of anatectic material. The anatectites are generally syntectonic and have been involved in all, or the greater part, of the deformational history of the migmatites (Figure 2A and D). They are invariably devoid of a significant mafic component although they may contain small amounts of muscovite or chlorite and, subsequently, have high SiO_2 (usually > 70%) and low Fe_2O_3 + MgO contents (≅ 1% or less).

The anatectites can be divided into two categories on the basis of their major element compositions. The first type, which is characteristic of anatectites from the migmatites shown in Figures 2B and C, have high SiO_2, low Fe_2O_3 + MgO and high K_2O values such that $K_2O/Na_2O \cong 1$ (Column 6, Table 1). The second type is similar except for the K_2O content which is much lower such that $K_2O/Na_2O \cong 0,1 - 0,2$ (Column 10, Table 1). These compositional characteristics are reflected simply in the presence, or absence of microcline. Because of their dominantly quartz-K-feldspar-plagioclase mineral assemblage the anatectites are suitably represented in the granite system Qtz-Ab-An-Or-H_2O and an assessment of the melt origin of these rocks can be made in terms of these components.

The compositions of a number of anatectites additional to those listed in Table 1 (that come from the migmatites represented in Figure 2) are plotted on Qtz-Ab-Or and An-Ab-Or ternary diagrams in Figure 5A and B respectively. The anatectites are plotted on two different ternary diagrams so that misrepresentation of their composition in terms of only a portion of the granite tetrahedron is minimized. Isotherms plotted in Figure 5 provide an estimate of the temperatures of melting for P_{H_2O} = 5 kb (after Luth et al., 1964 and Kleeman, 1965). They demonstrate the fact that the total temperature range over which isobaric cotectic melting may take place (i.e. where quartz-plagioclase solid solution - K-feldspar solid solution and melt are in equilibrium) is less than 50°C and, as Winkler and Lindemann (1972) have pointed out, is probably between 5-25°C depending on the melt composition.

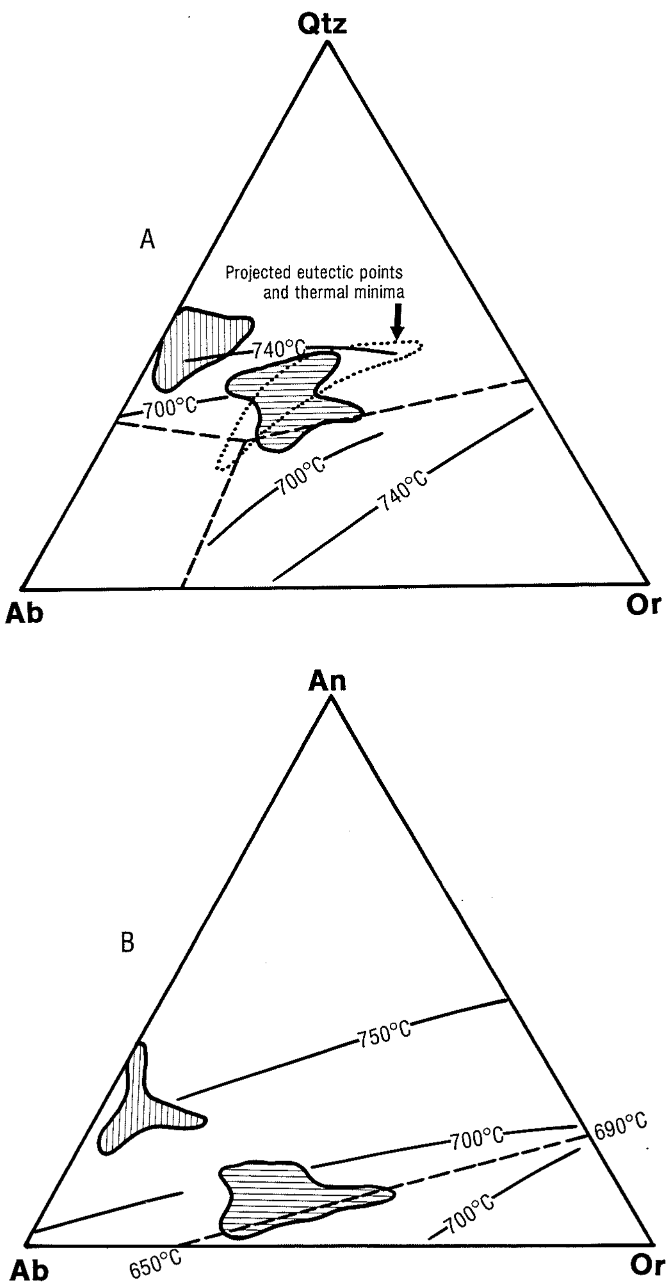

Figure 5 : Ternary plots of mesonormative Qtz-Ab-Or (A) and An-Ab-Or (B) showing the compositional fields of a number of anatectites in addition to those from Table 1. Isotherms and projected cotectic surfaces are from Luth et al. (1964) and Kleeman (1965). Vertical hatching is the field of Or-depleted anatectites (7 samples); horizontal hatching is the field of Or-rich anatectites (11 samples).

In Figure 5, the composition of the orthoclase (microcline)-rich anatectites fall in a field that roughly coincides with minimum-melt (or eutectic, at higher P_{H_2O}) compositions in the granite "system". In Figure 5A the field of Or-rich anatectites coincides with the envelope of projections of ternary eutectic points and thermal minima for a range for P_{H_2O} and Ab/An as defined by Luth et al. (1964) and von Platen (1965). In Figure 5B likewise, they coincide with the projected cotectic surface as defined by Kleeman (1965). In the granite tetrahedron, therefore, these anatectites will plot on, or near, the cotectic line where melt is in equilibrium with *three* coexisting phases (i.e. quartz-plagioclase solid solution-orthoclase). As such, these anatectites probably represent relatively small degrees of partial melt where the temperature of anatexis did not rise significantly above that where melting commenced. It can also be deduced that the parent rock must have contained plagioclase, quartz and, at least some, orthoclase in order that eutectic compositions could form (alternatively the parent may have contained a phase such as biotite that melted incongruently thereby resulting in K_2O-enriched melt). Such a parent might well have been a tonalite/trondhjemite gneiss which commonly contains ≅ 5% microcline.

The compositions of orthoclase (microcline)-depleted anatectites all plot in a field that is somewhat removed from minimum melt or eutectic compositions in Figure 5. In the granite tetrahedron these anatectites will undoubtedly lie in the orthoclase-depleted region where, according to projected isotherms, melt compositions have higher (by 40-50°C at P_{H_2O} = 5 kb) temperatures. Winkler and Lindemann (1972) and Winkler and Breitbart

(1978) have stressed that compositions of this nature cannot be precluded from having a magmatic or partial melt origin. This is because the composition of early melts will only remain on the cotectic line in the granite tetrahedron until such time as one of the equilibrium phases is used up and, therefore, the criterion that defines a magmatic melt is *not* its proximity to the isobaric cotectic. If a trondhjemitic parent with 5% orthoclase is considered and a partial melt consisting of equal proportions of quartz, plagioclase and orthoclase is derived from it, then it is obvious that as soon as melting exceeds 15% the melt composition will leave the cotectic and change in a direction *away* from the Or apex of the tetrahedron. Here the melt is in equilibrium with only two phases, namely plagioclase and quartz. Orthoclase-depleted anatectites may, therefore, represent higher degrees of partial melt of the same tonalitic/trondhjemitic parent from which the Or-rich anatectites were derived. Alternatively, they may have been derived from a dominantly plagioclase + quartz parent (plagiogranite), but such rocks are volumetrically insignificant in the region. These considerations support the field impression that the anatectites were derived by localized melting, probably of a tonalitic or trondhjemitic precursor, during the formation of the migmatitic zones. The degree of melting was variable and was probably facilitated by the dehydration of mafic greenstones in zones where magmatic activity prevailed.

V. AMPHIBOLITIC XENOLITHS AND DYKES

Most of the migmatitic outcrops studied are characterized by the presence of a mafic component, with the exception of that in Figure 2A where a metamorphosed felsic tuffaceous rock occurs as one discrete component of the migmatite. Mafic components of the migmatites can all be described as amphibolites as hornblende invariably constitutes the dominant mineral phase. In some of the more magnesian xenoliths poikiloblastic clinopyroxene occurs, whereas the tholeiite dykes of Type 3 migmatites are characterized by the presence of minor biotite in addition to hornblende. Most amphibolites contain small, but variable, amounts of plagioclase and quartz and, in some instances, accessory chlorite and sphene.

The following section compares the chemistry of amphibolites (meta-basalts) from the migmatite outcrops with that of basalts and tholeiites from the Barberton greenstone belt itself. Viljoen and Viljoen (1969b) originally defined a series of basaltic komatiites (i.e. specifically Barberton-, Badplaas- and Geluk-type basaltic komatiites with ≅ 10% MgO, ≅ 15% MgO and ≅ 20% MgO respectively) in the greenstone belt that were characterized by $CaO/Al_2O_3 > 1$. Other workers in Archaean greenstone belts have subsequently shown, however, that komatiites are not rigorously defined by $CaO/Al_2O_3 > 1$ and have used other features such as MgO content and quench textures to recognize these rocks (Arndt et al., 1977; Sun and Nesbitt, 1978). In the Barberton greenstone belt too, it has now been demonstrated that unaltered basaltic komatiites have a CaO/Al_2O_3 ratio that ranges between 0,86 - 2,5 whereas tholeiitic lavas vary between 0,66 - 0,85 (Smith and Erlank, 1978). Nevertheless, the Barberton basaltic lavas generally have a higher CaO/Al_2O_3 ratio than those, for example, from the Abitibi greenstone belt in Ontario (Arndt et al., 1977) and the distinction between komatiites and tholeiites in this study, is still taken, for convenience, to be at $CaO/Al_2O_3 = 1$.

Many of the amphibolitic xenoliths from the migmatites have the chemical attributes of Barberton-type basaltic komatiites (Table 1). Amphibolites from Type 1 and Type 2 migmatites have MgO contents ranging from 10 - 14% MgO with $CaO/Al_2O_3 > 1$ and low (< 0,8%) TiO_2. These rocks however, may also be tholeiitic in composition with lower MgO and CaO/Al_2O_3 and distinctly higher TiO_2 (sample D2, Table 1). All the xenoliths analysed are little altered apart from the effects of a retrogressive mineral assemblage and, where sampled, compositions have not been markedly changed by intruding felsic magma.

By comparison, the amphibolitic dykes that form the Type 3 migmatites have usually been partially assimilated and probably affected by residence contamination (Fratta and Shaw, 1974). Where relatively unaltered, the amphibolitic dykes have a composition that is similar to an average tholeiitic lava from the Barberton greenstone belt (Figure 6). Sample G1 (from the outcrop shown in Figure 2G) has a higher MgO content (11,4%) than most tholeiites but a $CaO/Al_2O_3 < 1$ (Table 1). By comparison other tholeiite dykes have lower MgO (4-8%, Table 1) but have compositions suggestive of assimilation or residence contamination. For example, samples E2 and F1 have higher K_2O contents (1,46% and 1,38% respectively) with concomitantly higher Rb concentrations (64 and 30 ppm) than those usually observed in komatiites. These compositions are probably due, in part, to the more evolved chemistry of the tholeiites as well as to assimilation and possible residence contamination.

The effects of assimilation and contamination have been noted in West Greenland in the pre-3,0 b.y. Ameralik dykes (Gill and Bridgwater, 1979). In Figure 6, the fields of unaltered (A) and altered (B) Ameralik dykes are shown on a plot of K_2O v CaO/Al_2O_3 and suggest a similarity in the composition of these dykes with those of the Type 3 migmatites. The relatively unaltered sample G1 plots close to A whereas the assimilated samples E2 and F1 plot in the field of B. Gill and Bridgwater (1979) have shown that Ameralik dykes range between 1,5 - 5,5% K_2O when intrusive into Amitsoq gneisses, by comparison with a range of 0,88 - 1,00% K_2O when intrusive into mafic supracrustals. They attributed this difference (which is only significantly noticeable in terms of K_2O) to residence contamination but, where the dykes have been deformed and metamorphosed these effects could equally be attributed to assimilation and migmatization.

In terms of the similarities in age, syntectonic character, chemical composition, effects of alteration and even the mutual presence of biotite (Gill and Bridgwater, 1979) it appears that the tholeiitic dykes of the Type 3 migmatites have a close analogue in the Archaean Ameralik dykes of West Greenland. These dykes, together with counterparts in the Lewisian of Scotland, have been described as the oldest known mafic magmatic event to have taken place within a crustal sialic environment.

VI. CONCLUSIONS

The study of migmatites in the region southwest of the Barberton greenstone belt has led to the recognition of three distinct types. The first type occurs where tonalitic or trondhjemitic magma has intruded and interacted with pre-existing greenstone (ensimatic) crust; a second type is characterized by the

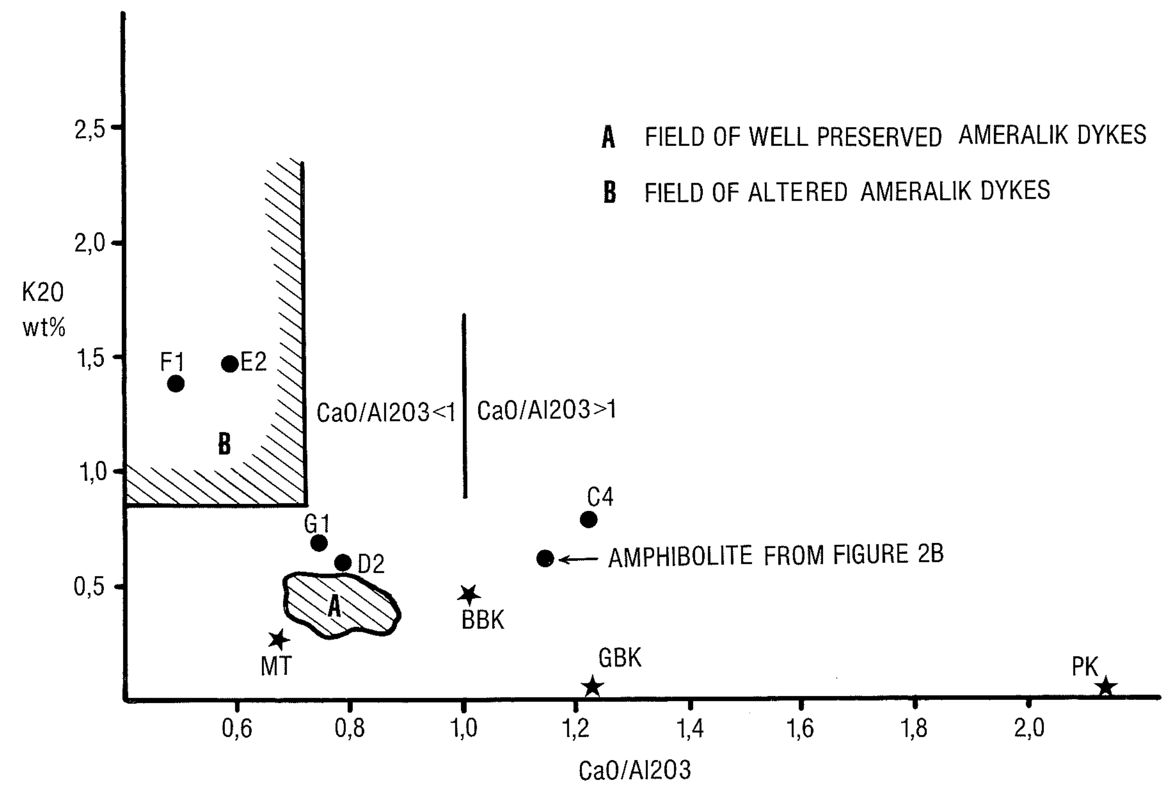

Figure 6 : *Plot of CaO/Al_2O_3 v K_2O for amphibolites from the migmatite outcrops described in the text. Individual samples plotted are from Table 1. Also shown are the fields of altered and unaltered Ameralik dykes from West Greenland (after Gill and Bridgwater, 1979) as well as average tholeiites, and basaltic and peridotitic komatiites from the Barberton greenstone belt. (MT - average meta-tholeiite; BBK - average Barberton-type basaltic komatiite; GBK - average Geluk-type basaltic komatiite; PK - average peridotitic komatiite - after Viljoen and Viljoen, 1969b).*

generation of significant amounts of anatectic material that intrudes both the gneiss and greenstone component and is, subsequently, responsible for migmatization; the third type occurs when tholeiitic dykes intrude pre-existing tonalite/trondhjemite (sialic) crust.

All the migmatites encountered have been affected, to a greater or lesser extent, by deformation. In places this has not been intense enough to obscure the primary relationships often preserved in the migmatite outcrops. In other instances, however, high stresses have resulted in a tendency to conform previously discordant contacts so that the distinction between deformed dykes and xenoliths is obscure.

Geochronological and field evidence indicates that the tonalite and trondhjemite gneiss plutons in the region are characterized by discrete, episodic emplacement, in the interval between ≅ 3,45 b.y. and ≅ 2,9 b.y. ago. The younger, and volumetrically dominant gneiss plutons intrude, and deform, the pre-existing ensimatic crust. They also intrude any older sialic crust irrespective of whether it pre-dated or post-dated the greenstones. Primary relationships between early ensimatic and sialic crust are only likely to be preserved, therefore, in migmatites that formed from the interaction of older tonalite/trondhjemite gneisses with the earliest greenstone successions. The study did not reveal any *unequivocal* relationships indicating that primitive komatiitic basalts were extruded onto, or that komatiitic feeder dykes were intrusive into, an earlier sialic crust.

Although their age is not known, mapping did reveal the presence of tholeiitic dykes which are clearly intrusive into pre-existing sialic crust. Although these dykes are relatively insignificant, their recognition has been obscured by their concordance with trondhjemite gneissosity in areas of high strain, and the fact that they are often assimilated in the same way as are mafic xenoliths in the region. These dykes may well represent an intrusive magmatic event that was coeval with the extrusion of the dominantly tholeiitic lavas found in the upper (and younger) portions of the Onverwacht pile in the Barberton greenstone belt. Like the Ameralik dykes of West Greenland, they are not considered to have been feeders to the greenstone assemblages, and the sial which they intrude cannot, therefore, be considered as a basement upon which the ensimatic crust was deposited.

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PLATE 1

A

Intrusive relationships between tonalite gneiss (left) and heterogeneous (migmatized) felsic meta-tuff (right) in a Type 1 migmatite.

B

Lit-par-lit array of anatectic veins intrusive into amphibolite in a Type 2 migmatite.

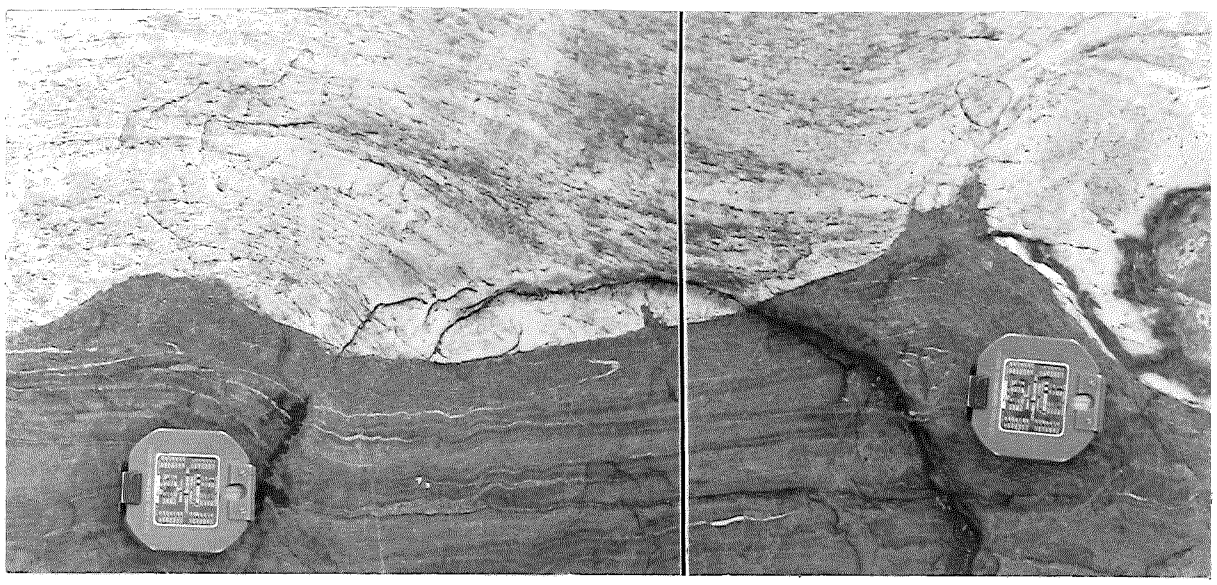
C

Portion of an assimilated tholeiite dyke intrusive into well-foliated trondhjemite gneiss

D

Discordant contact between trondhjemite gneiss and a possible tholeiite dyke in a Type 3 migmatite from the outcrop in Figure 2F. The emplacement of this dyke may have been controlled, in part, by pre-existing fractures.

E



Photograph illustrating the discordance between amphibolite and boudinaged banded trondhjemite gneiss at the outcrop shown in Figure 2.