ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

REGIONAL AND DETAILED FIELD AND GEOCHEMICAL STUDIES OF ARCHAEAN TRONDHJEMITIC GNEISSES, MIGMATITES AND GREENSTONE XENOLITHS IN THE SOUTHERN PART OF THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA

C. R. ANHAEUSSER and L. R. ROBB

INFORMATION CIRCULAR No. 125

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

REGIONAL AND DETAILED FIELD AND GEOCHEMICAL STUDIES OF ARCHAEAN TRONDHJEMITIC GNEISSES, MIGMATITES AND GREENSTONE XENOLITHS IN THE SOUTHERN PART OF THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA

by

C. R. ANHAEUSSER
(Senior Research Fellow, Economic Geology Research Unit)

and

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

ECONOMIC GEOLOGY RESEARCH UNIT

INFORMATION CIRCULAR No. 125

September, 1978.

South African Geodynamics Project Paper No. 35.

REGIONAL AND DETAILED FIELD AND GEOCHEMICAL STUDIES OF ARCHAEAN TRONDHJEMITIC GNEISSES, MIGMATITES AND GREENSTONE XENOLITHS IN THE SOUTHERN PART OF THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA

ABSTRACT

A wide variety of Archaean granites and greenstones occupy the extensive tract of country southwest of the Barberton greenstone belt. The greenstones, which occur as xenoliths wedged between numerous trondhjemitic gneiss diapirs, contain lithologies that are indisputably equatable with assemblages found in the lower formations of the Onverwacht Group. Intrusive into this environment are a complex suite of potash-rich granites of batholithic dimensions, as well as several smaller granitic and syenitic bodies. Mafic dykes of various ages also transect the region.

Field investigations show that complex areas of migmatite in the area are not randomly distributed but are intimately linked with the greenstone remnants and are probably the result of granite-greenstone interaction. It can furthermore be demonstrated on a variety of scales that, in certain places, lit-par-lit intrusion of the greenstones by the granites has taken place.

The mapping, in detail, of selected platform exposures has led to the recognition of a variety of granitic phases hitherto unrecognized in the district. At one locality two phases of trondhjemitic gneiss are recorded and the initial observations suggest that the earlier trondhjemite gneiss *may* pre-date the greenstone xenolith with which it is juxtaposed. A second exposure shows trondhjemite intrusive into an older felsic migmatite-gneiss unit which, it is suggested, may represent the migmatized equivalent of an acid tuffaceous rock unit from a typical greenstone assemblage.

This paper reports some of the findings to date and draws attention to some of the anomalies that exist in the region. Work still in progress should provide a greater understanding of the interactive processes between granites and greenstone and will result in a much refined model for the nature and development of the Archaean crust in the Barberton region.

* *

REGIONAL AND DETAILED FIELD AND GEOCHEMICAL STUDIES OF ARCHAEAN TRONDHJEMITIC GNEISSES, MIGMATITES AND GREENSTONE XENOLITHS IN THE SOUTHERN PART OF THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA

CONTENTS

* *

ISBN 0 85494 528 8

REGIONAL AND DETAILED FIELD AND GEOCHEMICAL STUDIES OF ARCHAEAN TRONDHJEMITIC GNEISSES, MIGMATITES AND GREENSTONE XENOLITHS IN THE SOUTHERN PART OF THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA

I. INTRODUCTION

The Archaean granitic terrane surrounding the Barberton greenstone belt is being investigated as part of South Africa's contribution to the International Geodynamics Programme. Field studies already completed north of the Barberton region have demonstrated that a wide range of granite types exist, including complex tonalitic gneisses and migmatites of several types and ages as well as a variety of homogeneous and intensely porphyritic granodioritic, adamellitic and granitic phases (Robb, 1977; van Nierop, personal communication, 1978).

In the south, regional mapping in the drainage system of the Komati River has revealed the presence of numerous greenstone xenoliths that have been traced for upwards of 50 km beyond the southern limits of the Barberton greenstone belt (Figure 1). These xenoliths, some of which are in excess of 10 km in length, disappear beneath younger sedimentary cover sequences but are known, from deep drilling, to extend for considerable distances to the south and southwest. The xenoliths display varying degrees of deformation, metamorphism, assimilation and migmatization. In extreme cases almost total granitization has occurred.

Several key areas have emerged from the regional mapping project and these have been singled out for detailed structural, geochemical and isotopic studies. Work in these areas is continuing but it is considered appropriate to report on some of the findings that have emerged to date and to set the scene for future communications applicable to the investigations. Mapping has been carried out on a variety of scales, with most of the regional information being compiled on 1:10 000 aerial photographs. At the other extreme small outcrop areas, such as selected river platforms, have been mapped on a scale of 1:50. This paper is aimed at providing a regional as well as a detailed look at some of the essential elements that make up the ancient granite-greenstone crust in the Barberton Mountain Land.

II. GENERAL GEOLOGY

The region investigated lies to the south and southwest of the Barberton greenstone belt (Figure 1), where the essentially granitic terrane occupies an area approximately 3 000 km^2 in extent. The region is dissected by numerous streams emanating from the Transvaal Drakensberg Escarpment in the west, where Proterozoic sediments form a platform sequence covering the basement granites. In the southwest the granitic terrane is partly covered by a thin veneer of Phanerozoic Karoo sediments.

A wide variety of granitic rock types have been identified in the region, the oldest of which are the tonalitic or trondhjemitic gneisses that occur commonly in the form of discrete diapiric plutons intrusive into the greenstones. The available U-Pb age determinations carried out by Oosthuyzen (1970) show a spread of ages ranging from 3 220 to 3 310 m.y. for some of the tonalitic gneiss plutons immediately flanking the Barberton greenstone belt. Follow-up Rb-Sr isotopic studies are currently in progress and have confirmed some of the earlier results. In addition, low initial $^{87}Sr/^{86}Sr$ ratios have been obtained (J.M. Barton, personal communication, 1978) which support the view that the early tonalite gneisses were probably derived from the partial melting of basaltic rocks at mantle depths - views that have been expressed by Barker et al (1976) and Condie and Hunter (1976) who based their ideas on rare-earth and trace element modelling techniques.

Numerous greenstone xenoliths rafted off the main body of the Barberton greenstone belt occur now as remnants of varying size wedged between the tonalitic gneiss plutons. The greenstone xenoliths, only the larger of which have been shown in Figures 1 and 2, display a wide range of lithological assemblages, including mafic and ultramafic metavolcanic rocks with subordinate felsic pyroclastic interlayers and minor siliceous metasediments, the latter of chemical sedimentary origin (banded cherts, banded iron-formations, calc-silicate rocks). There is now little doubt that these assemblages represent remnants of the lowermost stratigraphy of the Onverwacht Group as defined by Viljoen and Viljoen (1969) and which, in turn, forms the oldest recognizable supracrustal sequence on the Kaapvaal craton.

Intrusive into the tonalitic gneiss-greenstone terrane are a variety of potassic granites (coarse porphyritic granites, adamellites, granodiorites). Two main bodies, having batholithic dimensions, occupy extensive areas to the south and west of Badplaas and range in age from approximately 3 200 to 3 000 m.y. These bodies form topographically elevated areas relative to the flanking tonalitic gneisses and are also dissected by numerous streams flowing north and east.

A number of smaller potassic plutons intrude the tonalitic gneisses in the areas east and southeast of Badplaas. These include the Dalmein granodiorite pluton in the extreme east of the map area (Figure 1). This body has yielded U-Pb ages of approximately 3 200 m.y. based on studies on

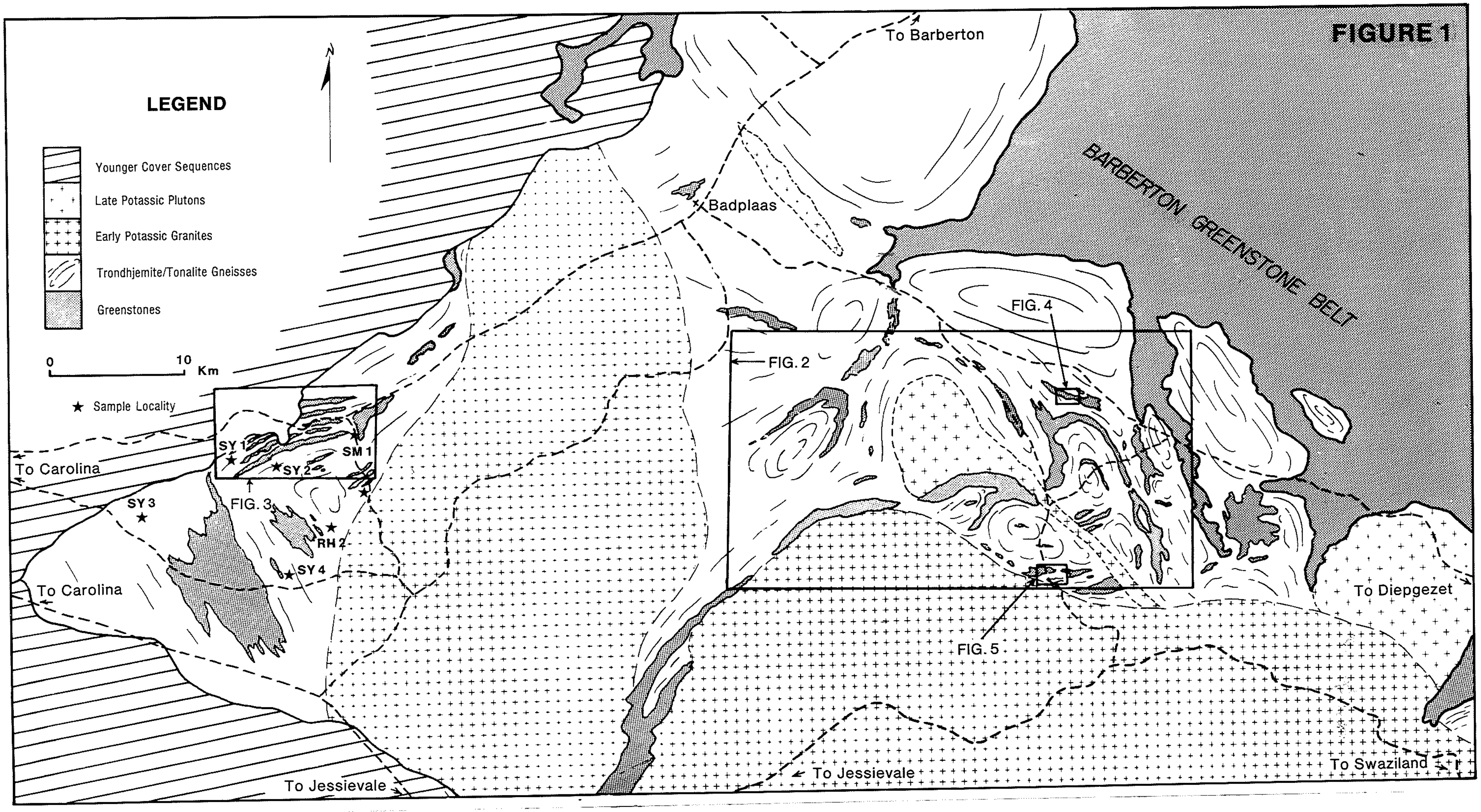


Figure 1 : Simplified regional geological map of the granite-greenstone terrane southwest of the Barberton greenstone belt. The oldest granitic rocks are the tonalitic or trondhjemitic diapiric gneiss plutons containing numerous greenstone xenoliths. Early potassic granite batholiths occupy extensive areas in the south and southwest, and later potassic plutons, including syenite bodies, occur in the region east and southeast of Badplaas. The figure also shows the localities of several areas selected for detailed study and described in the paper.

sphene and apatite (Oosthuyzen, 1970). Northwest of Lochiel is the Boesmanskop pluton which consists of medium-to-coarse-grained, in places porphyritic, syenite or quartz syenite. U-Pb age determinations suggest that this body is approximately 3 130 m.y. old (Oosthuyzen, 1970).

Intrusive into the entire region, but not shown on Figure 1, are numerous mafic dykes most of which are Proterozoic in age. A few younger dykes associated with post-Karoo igneous activity also occur in the area. The dykes have a predominant northwest trend and tend to swarm in places. Northeast and north-trending dykes are also present but are generally less prominent.

Numerous shear zones and major fractures are developed throughout the area and, like the dykes, are predominantly orientated in a northwesterly direction. Several thermal springs occur in the area, the principal one being located at Badplaas. These hot springs are aligned parallel to the major dyke and fracture directions and extend southeast of the map area into the neighbouring territory of Swaziland.

III. GEOLOGY OF THE AREA SURROUNDING THE BOESMANSKOP SYENITE PLUTON

Figure 2 illustrates the distribution and generalized character of some of the larger greenstone xenolithic remnants that occur in the vicinity of the Boesmanskop syenite body. Some of the larger xenoliths possess lithologies identical to, and traceable into, the basal stratigraphic units of the Onverwacht Group in the Barberton greenstone belt to the north.

Viljoen and Viljoen (1969) subdivided the lower Onverwacht stratigraphy into three main formations. The lower two formations (viz. the Sandspruit and the Theespruit) are commonly in juxtaposition with the intrusive tonalitic plutons in the type locality in the Komati River Valley. The third formation (Komati) is generally removed from the granite contacts and is probably not represented in the greenstone xenoliths shown in Figure 2. The lower Onverwacht stratigraphy is characterized by the presence of basaltic and peridotitic komatiite volcanic rock types most of which have been altered to a variety of amphibole, chlorite and talc schists as well as serpentinites. Subordinate, but stratigraphically important, interlayers of banded iron-formation and chert, felsic agglomerates and tuffs (mainly altered to quartz-sericite-fuchsite schists - the latter containing variable amounts of pyrophyllite, andalusite or sillimanite), and various calc-silicate rocks occur with the mafic and ultramafic assemblages.

Detailed mapping of some of the greenstone remnants in the regions flanking the Boesmanskop pluton (Anhaeusser, 1978) showed that all the components associated with either the Sandspruit or Theespruit formations of the Barberton belt are preserved and readily identifiable in the xenoliths, despite the superimposition of higher metamorphic grades and intensified structural complexity. In some cases banded cherty units have undergone total recrystallization and resemble quartzites. What were probably calcareous lenses in mafic tuffs have been altered into a variety of calc-silicate rocks, most of which display abundant quartz, diopside and feldspar, the latter often altered to epidote. Microcline is a common constituent of some of these rocks, as is garnet. Serpentinite bodies and lenses are prominent in some areas but the thin ultramafic layers are generally altered to talc or chlorite schists and do not outcrop prominently and can easily be overlooked. The felsic schists, where developed, consist mainly of quartz-sericite-schists but zones of agglomeratic material have been encountered in less-deformed remnants. Dominant in all the xenoliths are mafic metavolcanic assemblages. Usually the smaller remnants consist only of black hornblende-quartz amphibolites. In larger remnants, hornblende amphibolites are restricted to the peripheral areas in contact with the granites. Away from the marginal zones actinolite-chlorite assemblages may be encountered.

Table 1, columns 1-4, lists the composition of a number of mafic and felsic rock types encountered in the xenoliths shown in Figure 2. The amphibolite schists listed in Table 1 have been influenced by the granites flanking the remnants, as is indicated by the relatively high amounts of potassium and the generally low magnesian contents in sample BX2. The komatiitic nature of the metabasalts is apparent in amphibolites sampled at the Theeboom outcrop shown in Figure 4. Table 3, columns 1 and 2, show that the metabasalts possess chemical attributes that enable them to be grouped with the basaltic komatiites of the Barberton-type as defined by Viljoen and Viljoen (1969).

The greenstones are intruded by diapir-like bodies of leuco-tonalite or trondhjemite gneiss, being characterized by the assemblage quartz-plagioclase-biotite. Compositionally the tonalitic gneisses are extremely uniform, as may be judged from the examples listed in Table 1, columns 5-14, and whose localities are plotted on Figure 2. The soda-rich gneisses are almost invariably foliated parallel to the greenstone contacts, the foliation generally being more pronounced at the margins, becoming less apparent or disappearing entirely towards the centres of the larger diapiric plutons. Notably absent or only rarely developed (see later) are pegmatitic or K-rich phases.

The detailed field studies have revealed interesting relationships between the tonalitic gneisses and the greenstone remnants. Complex migmatite exposures occurring throughout the area and which have been used in arguments concerning the possible existence of a pre-greenstone ensialic crust will have to be carefully reconsidered in view of the findings. No longer may it be said that the migmatites in this region are haphazardly distributed throughout the entire granitic terrane.

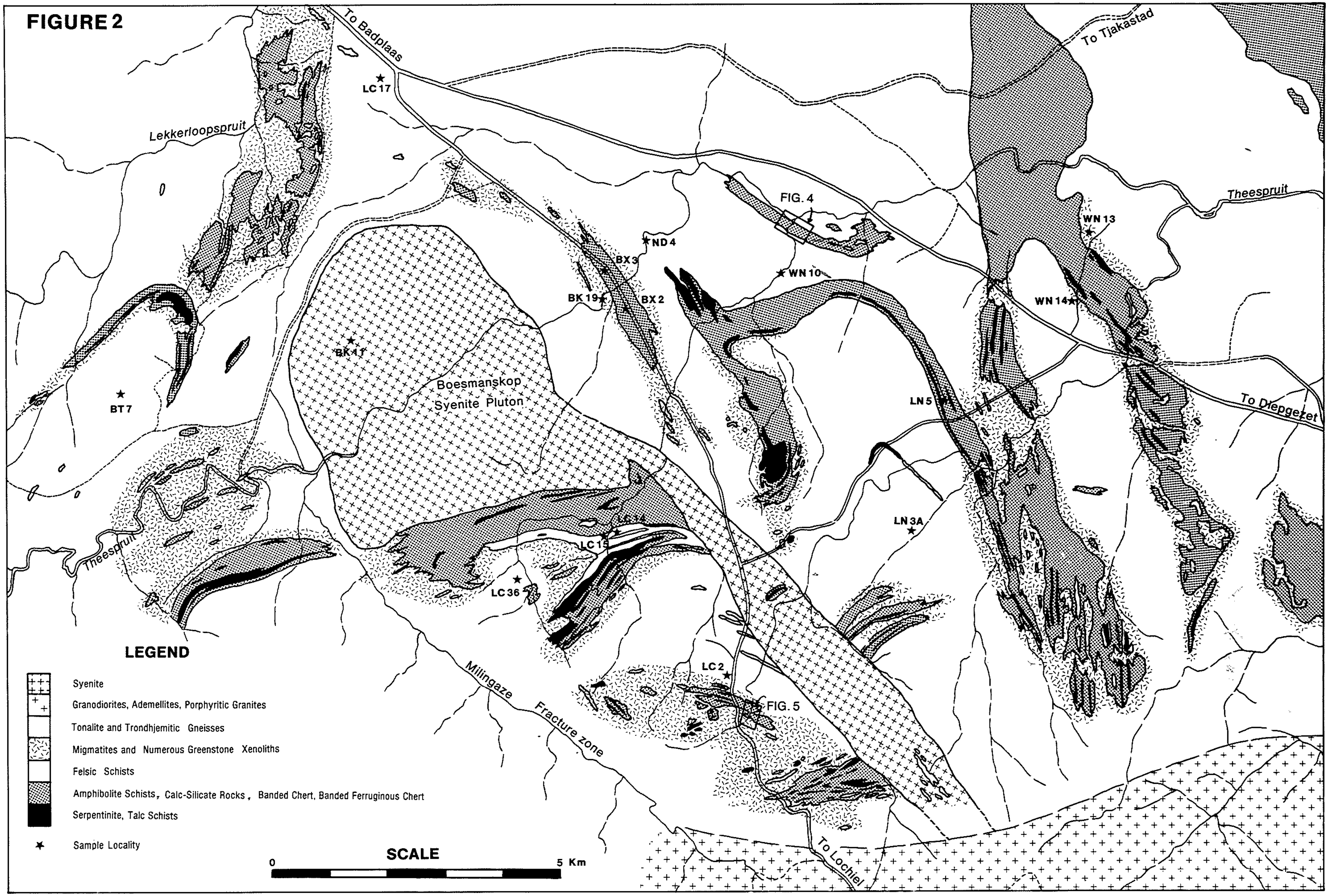


Figure 2 : Geological map of the granite-greenstone terrane in the vicinity of the Boesmanskop syenite pluton. The greenstone remnants are intruded by tonalitic or trondhjemitic gneisses resulting in the local development of complex migmatites.

TABLE 1

CHEMICAL ANALYSES OF SOME SELECTED ROCK TYPES FOUND IN GREENSTONE XENOLITHS, TOGETHER WITH LEUCO-BIOTITE TONALITE/TRONDHJEMITE GNEISSES IN THE AREA SURROUNDING THE BOESMANSKOP SYENITE PLUTON

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	BX 2ϕ	BX 3ϕ	LC14†	LN 5Ψ	BT 7Ψ	LC 2†	LC17†	LC36†	BK19†	ND 4Ψ	WN10Ψ	WN13Ψ	WN14AΨ	LN3AΨ	BK11†
SiO_2	52,10	49,20	76,08	69,20	74,51	71,26	71,13	66,05	68,91	74,48	72,33	72,98	71,03	71,37	58,07
TiO_2	1,02	1,06	0,20	0,17	0,18	0,20	0,21	0,64	0,23	0,18	0,30	0,21	0,35	0,31	1,06
Al_2O_3	14,30	13,50	12,80	11,40	15,53	15,94	16,01	17,18	16,84	15,41	15,16	14,35	15,24	14,33	14,98
Fe_2O_3	2,20	3,40	0,39	1,94*	1,12	0,35	0,43	0,62	0,42	0,69*	1,73*	1,70*	2,27*	2,62*	3,77
FeO	5,50	8,70	1,08	-	-	1,13	1,10	2,52	1,19	-	-	-	-	-	3,73
MnO	0,40	0,16	0,03	0,28	Nil	0,03	0,03	0,04	0,03	Nil	0,09	0,11	0,06	0,05	0,19
MgO	5,80	6,90	0,62	3,30	0,60	0,62	0,66	1,33	0,83	0,40	0,84	1,28	0,73	1,11	2,24
CaO	12,80	11,90	0,78	6,65	2,30	2,34	2,45	3,31	2,99	1,88	2,28	2,35	2,60	2,91	4,19
Na_2O	0,90	2,90	4,38	1,60	3,86	5,45	5,36	5,25	5,96	4,38	4,95	4,85	4,88	3,91	4,26
K_2O	3,64	0,79	2,79	4,07	1,76	1,68	1,72	1,54	0,94	2,47	1,81	1,87	2,16	1,97	5,53
P_2O_5	0,08	0,10	0,03	0,05	0,10	0,07	0,07	0,22	0,10	0,06	0,13	0,04	0,07	0,03	0,80
H_2O^+	1,00	1,10	0,55	0,73	0,78	0,66	0,60	0,93	0,72	0,60	0,67	0,38	0,77	0,78	0,41
H_2O^-	0,10	0,05	0,10			0,10	0,12	0,11	0,20						0,26
CO_2	Nil	Nil	0,16	-	-	0,03	0,14	0,16	0,04	-	-	-	-	-	0,06
Totals	99,84	99,76	99,99	99,39	100,74	99,86	100,03	99,90	99,40	100,55	100,31	100,12	100,14	99,39	99,55
Ba ppm	-	-	896	-	209	566	572	562	500	552	443	349	437	243	2350
Sr ppm	-	-	93	-	-	790	766	868	1150	-	723	593	659	-	2000
Rb ppm	-	-	89	-	-	62	54	71	40	-	47	63	58	-	140
Zr ppm	-	-	225	-	-	192	192	300	100	-	-	-	-	-	220

Analysts : † National Institute for Metallurgy, Randburg ϕ Bergström and Bakker, Johannesburg
Ψ University of the Witwatersrand, Johannesburg
* Total Fe as Fe_2O_3

Columns : 1 - 2. Amphibolite schists (hornblende-diopside-plagioclase-quartz-microcline-epidote).
3. Schistose felsic tuff (quartz-sericite-biotite-microcline-plagioclase).
4. Calc-silicate rock (quartz-diopside-microcline ±-garnet).
5 - 14. Leuco-biotite tonalitic/trondhjemitic gneisses.
15. Boesmanskop syenite pluton.

Examination of Figure 2 shows that the areas of migmatite development are almost invariably situated in close proximity to greenstone xenoliths. More specifically, some of the most prominent migmatite exposures are located along the projections of the greenstone relics and appear to be the result of a complex process of granitic interaction with the greenstones. The area is particularly informative in this regard as progressive stages of granitization and migmatization can be demonstrated. These range from the simple lit-par-lit injection of the tonalitic gneisses along the schistosity planes of the amphibolites and other components of the greenstone remnants (Plate 1) to successive stages of granitization and assimilation and the eventual development of a variety of migmatitic textures (Plates 2 and 4).

This variety in the migmatite textures, reflected mainly by changes in the nature and composition of the components seen in the exposures, appears to be due to the initially variable compositions of assemblages making up the stratigraphy of the affected greenstones. Thus while metabasaltic rocks predominate and impart to the migmatites their characteristic amphibolitic layers, bands, or lenses, the more felsic components, often associated with the xenoliths, are generally overlooked as these merge more subtly with the invading granites. This is so, particularly in view of the fact that they generally form the lowest melting fraction in the assimilatory process and appear to be readily reconstituted into granite-like veins, sheets, or dykes that contribute to the overall complexity experienced in migmatite outcrops.

A wide range in the degrees of partial melting, assimilation, palingenesis, and rheomorphism can be demonstrated in the area and will form the subject matter of future communications from the region. An example, still being investigated in detail, is discussed later in this paper when reference is made to the findings from the Weergevonden exposure (Figure 5). Illustrations providing visual evidence of some of the stages seen in the migmatization of greenstone relics found in the Badplaas region are shown in Plate 2.

Later potassic granitic and syenitic rocks intrude the tonalitic granite-greenstone terrane. As mentioned earlier, porphyritic and homogeneous granodiorites, adamellites, granites and syenites occupy large tracts south of the area shown in Figure 2. The Boesmanskop syenite pluton provides a striking topographic feature in the generally low-lying tonalitic gneiss terrane. The main body straddles the Theespruit River and consists of a medium-to-coarse-grained syenite, locally porphyritic, particularly around the northwestern and northern rim of the pluton. Table 1, column 15, provides a typical analysis of the syenite which contains microcline, microperthite, plagioclase, hornblende-actinolite, biotite, augite, quartz and accessory minerals apatite, sphene, zircon, allanite and magnetite. Many of the large feldspar crystals are prominently zoned, and exsolution perthites, myrmekites, and graphic quartz-feldspar intergrowths are commonly encountered (Anhaeusser, 1974, 1975).

The Boesmanskop syenite body has a narrow 'tail' extending in a southeasterly direction where its relationship with the potassic granites in the south is obscured by an extensive diabase sheet. The Boesmanskop pluton appears to be analogous to the syenites described from the Archaean terrane of northern Minnesota, e.g. the Icarus and Linden plutons (Goldich et al., 1972; Hanson and Goldich, 1972; Prince and Hanson, 1972). These bodies have initial $^{87}Sr/^{86}Sr$ ratios of 0,7009 and are considered to have formed by partial melting or differentiation of basic rocks. Preliminary data from the Boesmanskop syenite yielded an initial $^{87}Sr/^{86}Sr$ ratio of 0,7010 (B. Ryan, personal communication, 1974), suggesting that these rocks also may have formed in a manner similar to those in Minnesota. However, further more detailed isotopic work is at present being carried out on this and other plutons in the area.

The emplacement of the various bodies of potassic granite led to the widespread obliteration of the tonalite-greenstone terrane south of the area shown in Figure 2. The potassic granites, particularly where they abut against greenstone remnants, have been responsible for the development of a second generation of migmatite - these being essentially potassic migmatites relative to the type described earlier and which are predominantly sodic migmatites. Migmatites of a type intermediate between the two are also developed where pegmatitic and aplitic dykes and veins invade some of the exposures. A general observation, made at such localities, suggests that the migmatites are far more contorted and granitized wherever pegmatites have introduced potassium into the system and the migmatites show a tendency of becoming progressively more homogeneous, both texturally and compositionally.

IV. GEOLOGY OF THE ROOIHOOGTE PASS AREA

The Rooihoogte Pass area provides outcrops of tonalitic gneiss and greenstone remnants exposed immediately east of the Transvaal cover sequences between Badplaas and Carolina (Figures 1 and 3). The general geological description provided for the area surrounding the Boesmanskop syenite pluton is equally applicable in this region which contains some extensive areas of greenstone containing mainly metabasaltic schists as well as serpentinites and a variety of magnesium-rich schists (talc-chlorite-tremolite).

Intrusive into the area are tonalitic and trondhjemitic gneisses which, as can be seen in Table 2, are consistently uniform in composition over the entire region (sample localities plotted on Figure 1).

Figure 3 provides a closer examination of the field relationships between the tonalitic gneisses and the greenstones. Absent in this region are any obvious diapiric plutons. Instead, the area selected for discussion here shows an intricate lit-par-lit invasion of the greenstones by parallel tongues of foliated gneiss. Within the essentially metabasaltic units, which consist almost entirely of hornblende-quartz assemblages, are smaller tongues and pods of tonalite as well as intricate granitizing veins and crosscutting dykelets of tonalite - the entire mass seemingly being gregariously assimilated by the invading granitic rocks. Complex migmatite exposures occur throughout the area but are best seen in river sections, particularly in the northeast of the map area. The greenstones display strongly developed schistosities and are isoclinally folded in places. The presumed mechanism of granite emplacement is thought to have been the invasion of the greenstones along steeply inclined schistosity planes and more specifically along isoclinal fold axes.

The suggestion has also been made that the entire region reflects tectonically infolded slices and that the structures and relationships seen in the region can be explained in a manner other than by igneous intrusion of the gneissic granites. Whether or not this explanation can account for all the features seen in the area remains to be evaluated. The area does, however, provide an example of lit-par-lit-type field relationships on a mega-scale. By contrast, the same lit-par-lit relationships can be demonstrated in numerous other localities throughout the area shown in Figure 1. On a scale of a river platform,the size of which may be measured in terms of 10-12 metres,is the spectacular lit-par-lit banding at the Theeboom outcrop located in Figures 1 and 4. Here, as shown in Plate 1A, is displayed essentially the same relationship as seen in the Rooihoogte Pass area.

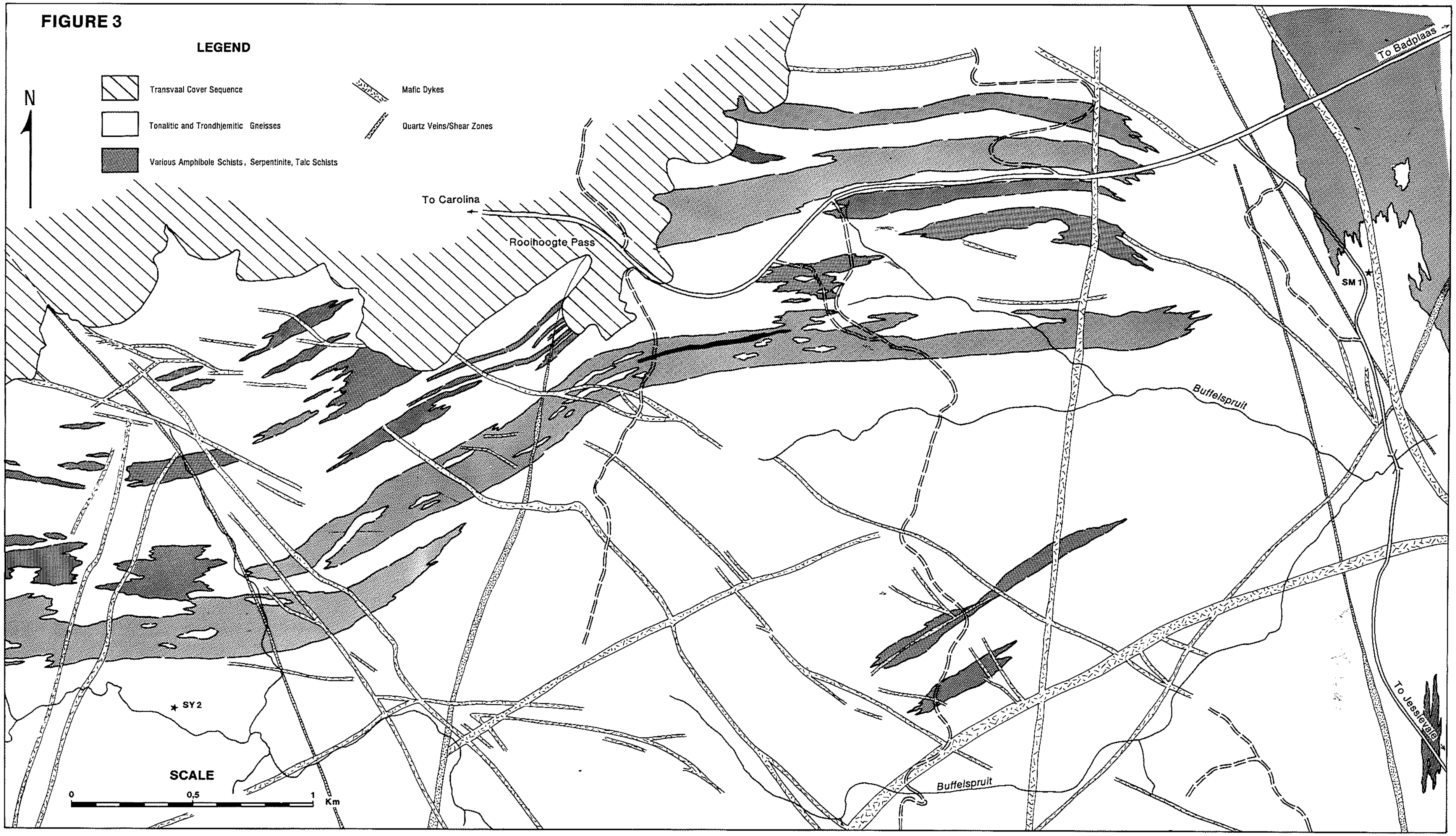


Figure 3 : Geological map of the Rooihoogte Pass area showing the large-scale 'lit-par-lit' relationship of the trondhjemitic gneisses and the greenstone xenoliths in the area.

TABLE 2

CHEMICAL ANALYSES OF FOLIATED LEUCO-BIOTITE TRONDHJEMITIC GNEISSES INTRUDED INTO GREENSTONES IN THE ROOIHOOGTE PASS AREA

	1	2	3	4	5	6	7	8
	SY1	SY2	SY3	SY4	RH2	SM1	SM2	AVE
SiO_2	70,84	71,01	73,94	71,41	68,55	69,94	68,97	70,67
TiO_2	0,31	0,33	0,21	0,24	0,36	0,40	0,51	0,34
Al_2O_3	15,97	14,98	15,27	15,24	16,31	16,05	16,40	15,75
Total Fe as Fe_2O_3	2,30	3,37	0,92	2,22	2,65	2,77	2,73	2,42
MnO	0,08	0,05	0,03	0,14	0,04	0,07	0,02	0,06
MgO	1,15	1,19	0,40	0,98	1,34	1,21	1,47	1,11
CaO	3,02	3,39	1,50	3,36	3,76	2,96	3,79	3,11
Na_2O	4,00	4,13	5,20	4,25	3,82	4,31	4,01	4,25
K_2O	2,42	1,39	1,93	1,26	1,24	1,42	1,19	1,55
P_2O_5	0,11	0,05	0,07	0,04	0,11	0,10	0,14	0,08
L.O.I.	0,75	0,89	0,85	1,35	1,12	1,25	0,89	1,01
Totals	100,96	100,77	100,33	100,50	99,30	100,49	100,11	
Ba ppm	303	1533	258	149	495	211	154	
Sr ppm	-	541	-	-	575	-	-	
Rb ppm	-	45	-	-	36	-	-	

Analyst : University of the Witwatersrand, Johannesburg.

Taken a step further the lit-par-lit relationship can be seen scaled down in successive stages to portions of outcrops (Plate 1 B, C) as well as to hand specimen-sized examples (Plate 1D). The same relationship can also be demonstrated on a microscale both in the field and under the microscope.

V. DETAILED STUDIES OF SELECTED EXPOSURES

The regional mapping programme has been complemented by detailed studies of selected, well-exposed outcrops in some of the water-worn river channels in the area. These studies have led to the recognition of granitic phases, some of which have hitherto not been recognized. The brief descriptions provided in the following sections outline some of the new data that has emerged from these areas.

A. The Theeboom Outcrop

On the farm Theeboom (Figures 1 and 4) the contact relationships between a large, linear, amphibolitic body and a surrounding suite of trondhjemitic gneisses have been exposed along an extensive water-worn platform. Selected areas along this platform have been mapped on a scale of 1:50 (Figure 4).

The linear amphibolitic body is identical in appearance and composition to basaltic komatiites found in the type area of the adjacent Barberton greenstone belt. The characteristic composition of this rock unit (e.g. $CaO/Al_2O_3>1$) is shown in Table 3, columns 1-2. Intrusive into the amphibolite are two distinct episodes of quartzo-felspathic veins. The first episode of veining, which has been involved along with the structural deformation of the amphibolites, principally in the form of lateral extension and boudinaging (Plate 3A), is characterized by high SiO_2 contents low K_2O/Na_2O ratios and very low Rb and Ba contents (Table 3, column 6). Such rocks are very similar in composition to the oceanic plagiogranites described by Coleman and Peterman (1975). These rocks contain significantly less K_2O and Rb than continental tonalites and trondhjemites and are generally considered to form an integral part of ophiolite assemblages. Although there is no consensus as to their origin, Coleman and Peterman (1975) consider them to have formed as the result of

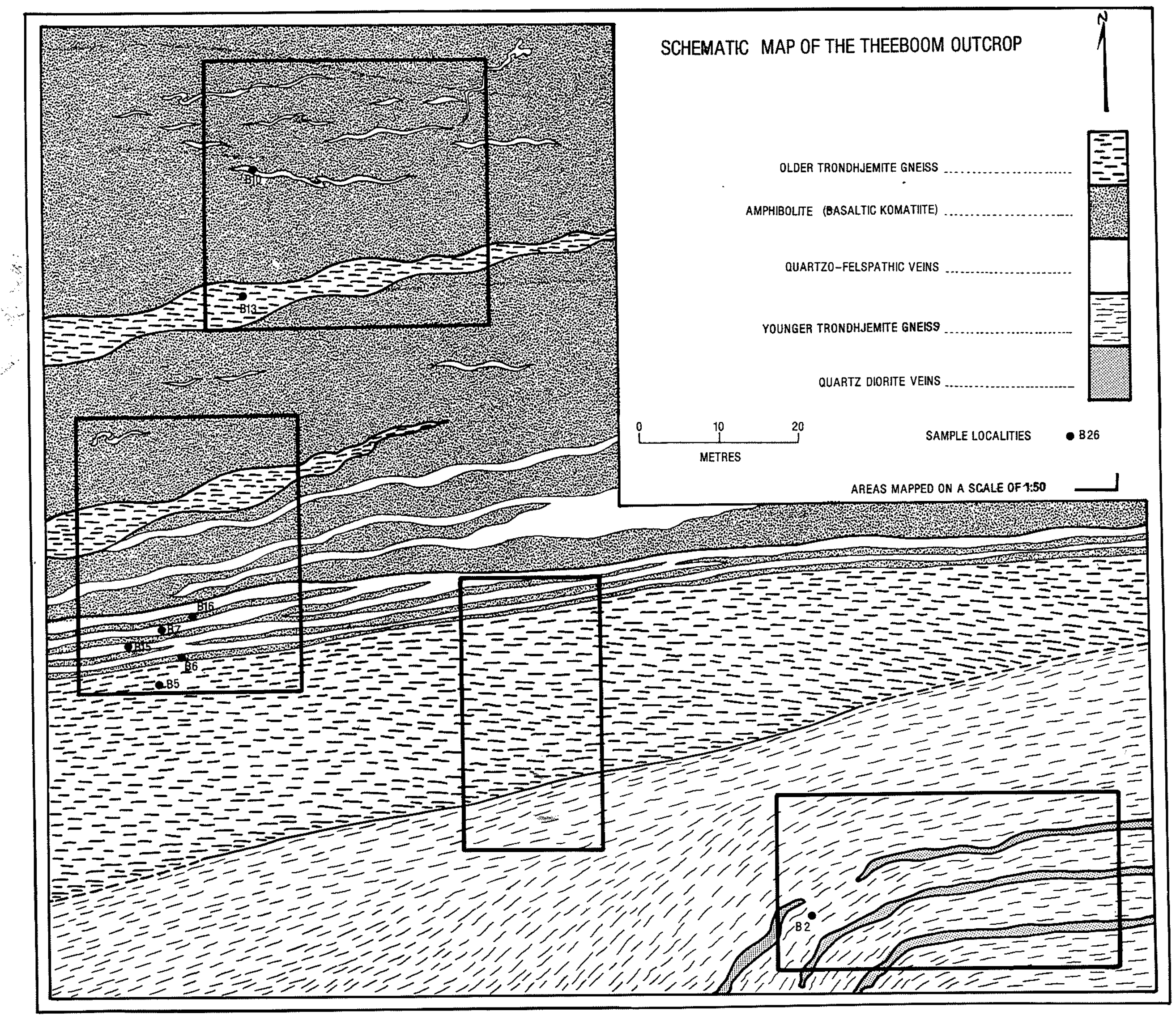


Figure 4 : A schematic geological map of the Theeboom outcrop showing the relationships between the amphibolite and the older and younger trondhjemite gneisses.

differentiation of subalkaline basalts. Work currently in progress may determine whether the quartzo-feldspathic veinlets encountered at the Theeboom outcrop are analogous to plagiogranites in their ophiolite setting.

The later quartzo-feldspathic veinlets (Plate 1A) have not been boudinaged and are characterized by lower silica contents, K_2O/Na_2O ratios approaching unity and considerably higher Rb and Ba contents (Table 3, columns 7-8). Furthermore, these veins contain sillimanite and may possibly represent the anatectic products of very early sialic crust (Robb, in preparation).

Occurring in juxtaposition with the amphibolites, and also as discrete dyke-like bodies within the latter (Figures 4 and 6), is a very well-foliated trondhjemite gneiss. As seen in Figure 6 and Plate 3B the prominent foliation within the trondhjemite gneiss is, in places, truncated by the amphibolite. This suggests that the trondhjemite gneiss pre-dates the amphibolite and, in the case of Figure 6, actually occurs as a xenolith within it. An alternative possibility is that the foliation relationships observed are actually the result of cleavage refraction that has occurred during the deformation of two materials of differing competencies. As the relationship is of primary importance in terms of crustal evolution a final statement on the matter is to be reserved until geochronological, and other work is completed.

Proceeding southwards, away from the amphibolitic body in the river section, a sharp and well-defined contact between the early trondhjemitic gneiss and a later, less-well-foliated, trondhjemitic gneiss is traversed (Plate 3C). As is seen in the illustration the foliation, as well as discrete anatectic veinlets within the older trondhjemitic gneiss, are clearly truncated by a large body (perhaps a diapir) of younger trondhjemite gneiss whose foliation parallels the contact between the two. A comparison of the composition of the older and younger trondhjemite gneiss (Table 3, columns 3-5) shows that the two units have a very similar major element chemistry. In addition, the Rb and Ba contents of the two rock types are very similar. However, the Sr contents appear to be different in that the older trondhjemite gneiss has lower Sr concentrations than the younger trondhjemite gneiss. This is emphasized in Table 4 where analyses are presented of trondhjemites whose relative ages are known, either by virtue of physical relationships or geochronology. The inverse relationship between Sr and age within these trondhjemitic bodies is known to occur elsewhere in the area, albeit where the geological control is not as rigid. Apart from Sr content, the pronounced foliation of quartz and biotite in the older trondhjemite compared to

TABLE 3

CHEMICAL ANALYSES OF VARIOUS ROCK TYPES FROM THE THEEBOOM OUTCROP

	1	2	3	4	5	6	7	8
	B6	B16	B5	B13	B2	B10	B7	B15
SiO_2	50,54	50,15	73,43	74,62	72,70	77,52	73,93	73,43
TiO_2	0,73	0,58	0,19	0,19	0,25	0,06	0,12	0,12
Al_2O_3	9,40	8,14	15,20	14,95	15,42	14,19	14,87	14,96
Fe_2O_3	13,47	12,66	1,21	1,47	1,56	0,19	1,05	0,88
MnO	0,46	0,34	0,09	0,04	0,12	0,01	0,04	0,01
MgO	10,47	11,87	0,51	0,38	0,46	0,06	0,51	0,44
CaO	11,52	11,62	1,87	1,76	2,30	1,54	1,51	1,12
Na_2O	1,75	1,82	4,73	5,23	5,32	6,46	4,69	4,59
K_2O	0,79	0,60	2,22	1,44	1,45	0,53	4,24	4,10
P_2O_5	0,01	0,01	0,08	0,08	0,11	0,02	0,07	0,07
L.O.I.	1,02	1,11	0,26	0,48	1,41	0,39	0,64	0,60
Totals	100,16	98,99	99,79	100,64	101,10	100,97	101,67	100,32
Rb ppm	14	15	53	69	52	14	140	97
Sr ppm	184	82	674	660	712	81	337	339
Ba ppm	75	34	390	458	226	5	499	521

Analyst : L.J. Robb
Total Fe as Fe_2O_3

Columns :
1 - 2. Amphibolites (Barberton-type basaltic komatiite)
3 - 4. Older trondhjemitic gneisses
5. Younger trondhjemitic gneiss
6. Early intrusive quartzo-felspathic veinlets
7 - 8. Late intrusive quartzo-felspathic veinlets

TABLE 4

Sr CONTENTS OF OLDER AND YOUNGER TRONDHJEMITIC GNEISSES FROM THE THEEBOOM AND WEERGEVONDEN EXPOSURES

Sample Numbers	A1*	B21*	B12A*	B23*	B5	B13	Average
Older Trondhjemite Gneisses	553	574	604	581	674	660	608

Sample Numbers	B2	C2	B20*	Average
Younger Trondhjemite Gneisses	712	754	810	759

* Sample localities not plotted on accompanying maps

the less well-developed platy mineral foliation in the younger trondhjemite (Plate 3C) provides a means of determining the difference between the two trondhjemite types.

The detailed mapping of the Theeboom outcrop has led to the recognition of a granitic event hitherto unrecognized in the region. Although confirmatory work is necessary it is possible that the trondhjemite gneiss may represent an early event in the formation of the sialic crust predating the major tonalitic diapirism characteristic of the area. An alternative explanation may be that the two trondhjemitic phases provide support for the existence of polydiapirism or "diapirs within diapirs" as suggested by Stephansson (1975). Until such time as the two trondhjemitic phases can be satisfactorily dated it would be hazardous to speculate on the implications of these relationships in terms of crustal evolution.

B. The Weergevonden Outcrop

In the Weergevonden area (Figures 1 and 5) a water-worn platform reveals an outcrop consisting of a heterogeneous gneiss-migmatite and a younger homogeneous tonalitic gneiss which intrudes the older gneiss-migmatite.

The heterogeneous gneiss-migmatite is characterized by differing degrees of deformation; as seen in Figure 5 the western section of the outcrop exhibits tight isoclinal folding, this deformation diminishing in intensity towards the east. In the eastern portion of the outcrop the migmatite gneiss unit has an essentially linear character where discrete anatectic veinlets, commonly ptygmatically folded, occur within a fine-grained equigranular granodioritic parent. Proceeding along strike, therefore, one can readily assess the effects of differing degrees of structural deformation on a single rock unit, and gain insight into the actual process of migmatization. As the heterogeneous gneiss-migmatite becomes increasingly deformed, it takes on a different physical appearance, becoming coarser-grained and having a schlieric texture. Anatectic veinlets are particularly numerous compared to the relatively undeformed area and the distinct fine-grained granodioritic parent is no longer easily discernible (see Figure 5 and compare Plate 4A,C and D). There is no doubt that genetically the undeformed heterogeneous gneiss is identical to the deformed heterogeneous migmatite and this is borne out by their similar respective chemical compositions (cp. columns 1 and 2, Table 5). The relationship between migmatization processes and structural deformation has long been recognized (Wegmann, 1929; Mackenzie, 1957) and it is suggested that this outcrop illustrates the affinity between these two parameters on a small scale.

Figure 5 : Segmented geological map showing a sequence of exposures at the Weergevonden outcrop. The transgression along strike from isoclinally folded heterogeneous gneiss-migmatite in the west, to relatively undeformed heterogeneous gneiss in the east, is demonstrated. Younger tonalitic gneiss intrudes the heterogeneous gneiss-migmatite.

As previously mentioned, the homogeneous tonalite gneiss intrudes the older heterogeneous gneiss-migmatite (Figure 5 and Plate 4B). The chemistry of the former (Table 5, column 5) is clearly different to that of the latter, having a lower K_2O/Na_2O ratio and a lower Ba content, but containing considerably higher amounts of Sr.

It has been emphasized in this paper that zones of migmatite development are not random but occur in areas where intrusive tonalitic material has interacted with pre-existing mafic or ultramafic greenstones. In this light, the Weergevonden outcrop represents an enigma in that intrusive tonalitic material has intruded a pre-existing felsic migmatite-gneiss *per se*. To explain this situation two possibilities present themselves; firstly that the gneiss-migmatite represents sialic crust that predates the extensive intrusion of tonalitic diapirs in the area and in this sense may be equatable with the older trondhjemite gneiss described in the Theeboom outcrop, or secondly, that it represents migmatized felsic rock that once formed part of a typical greenstone lithology. The second suggestion

TABLE 5

CHEMICAL ANALYSES OF VARIOUS ROCK TYPES FROM THE WEERGEVONDEN OUTCROP

	1	2	3	4	5
	C3*	C4*	LC14†	LC15†	C2*
SiO_2	74,29	74,80	76,08	73,14	68,77
TiO_2	0,20	0,23	0,20	0,25	0,52
Al_2O_3	12,66	13,10	12,80	12,95	17,18
Fe_2O_3	2,18	2,22	1,47	2,40	3,22
nO	0,01	0,05	0,03	0,06	0,01
MgO	0,78	0,80	0,62	0,97	1,14
CaO	0,87	1,12	0,78	2,46	3,09
Na_2O	3,77	2,80	4,38	3,08	4,45
K_2O	3,86	3,40	2,79	2,87	1,51
P_2O_5	0,06	0,04	0,03	0,05	0,18
L.O.I.	0,49	0,74	0,81	1,71	0,85
Totals	99,17	99,30	99,99	99,94	100,92
Rb ppm	88	134	89	121	58
Sr ppm	100	185	93	90	754
Ba ppm	845	975	896	789	220

Analysts : † National Institute for Metallurgy, Randburg
* L.J. Robb

Columns :
1. Heterogeneous gneiss-migmatite
2. Structurally deformed heterogeneous migmatite
3 - 4. Acid tuffaceous rocks
5. Younger intrusive tonalite gneiss

appears feasible when the composition of acid tuffaceous rocks from a large greenstone xenolith near the Weergevonden outcrop is compared with that of the heterogeneous migmatite-gneiss (cp. columns 1-2 with columns 3-4, Table 5). Further work is required, however, before emphatic statements concerning the origin of the heterogeneous gneiss-migmatite can be made. Clearly though, the involvement of felsic units of typical greenstone lithologies in the formation of complex migmatitic rocks is an interesting notion in this region, and if proved correct would provide valuable evidence for the suggestion that most migmatites in the area are of arteritic origin.

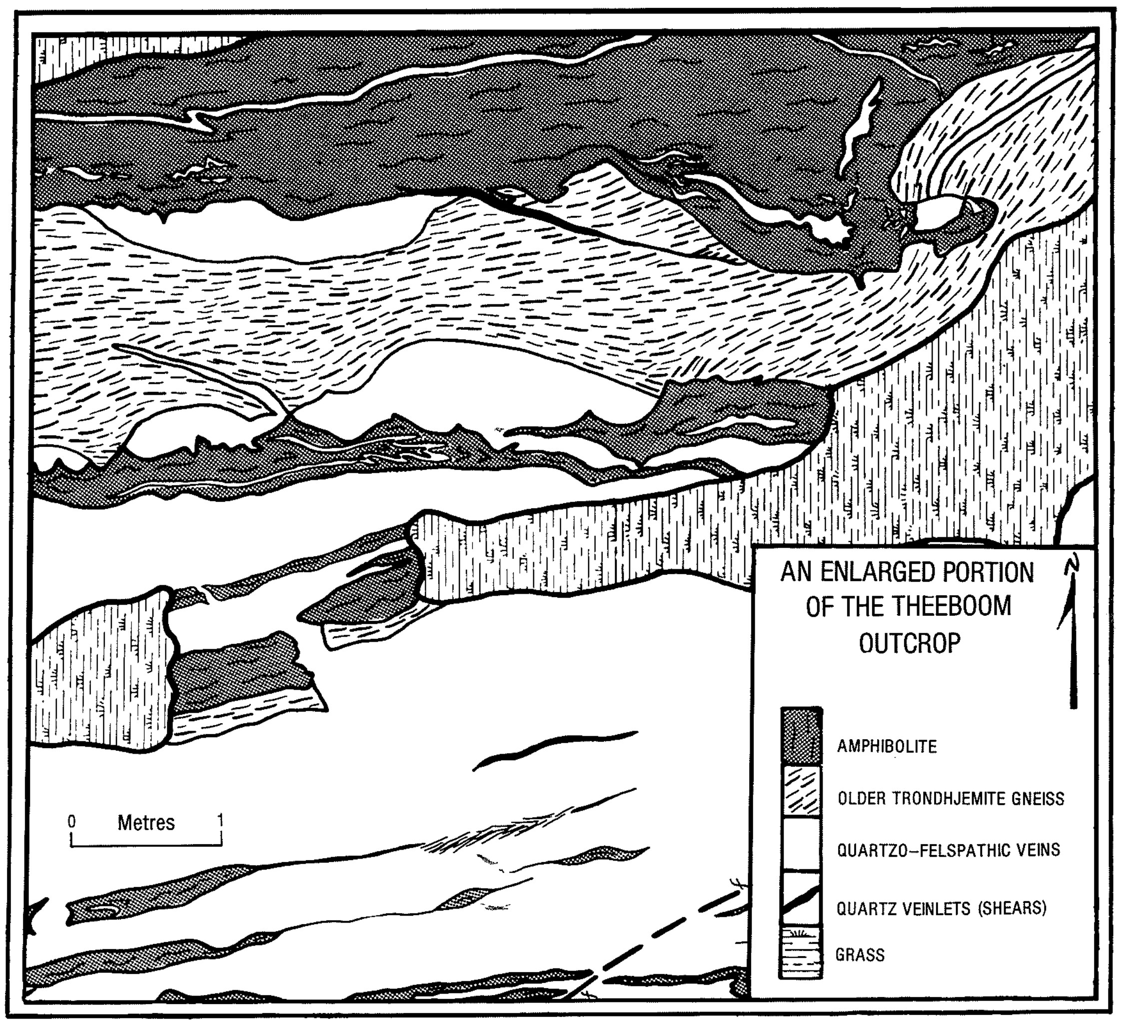


Figure 6 : Enlarged map of a small portion of the Theeboom outcrop illustrating the relationship between the foliation in the older trondhjemite gneiss and the amphibolite. At this locality the foliation in the gneiss is truncated by the amphibolite.

VI. DISCUSSION AND CONCLUSIONS

The area south of the Barberton greenstone belt provides a wide spectrum of granite-greenstone events and should contribute materially to the understanding of Archaean crustal evolution on the Kaapvaal craton. The region is particularly instructive as it affords the opportunity to examine, on a variety of scales, the complex relationships between the granites and numerous greenstone xenoliths scattered throughout the region.

The greenstone xenoliths show a wide range of lithologies that enable them to be indisputably correlated with rocks of the lower division of the Onverwacht Group in the Barberton greenstone belt which is situated to the northeast of the area studied. These xenoliths display varying degrees of metamorphism, assimilation and migmatization and it is possible to monitor the progressive stages of alteration and granitization affecting the supracrustal assemblages.

The detailed mapping has revealed the existence of at least two generations of tonalite or trondhjemite but as yet the absolute ages of these rocks remains to be determined. Furthermore, the migmatites exposed throughout the region can now be convincingly shown to conform to a predictable pattern, being consistently located in close proximity or adjacent to greenstone remnants. The migmatite textures appear to have originated by progressive stages of granite-greenstone interaction and the ongoing investigations will be designed to establish a clearer understanding of the processes leading to migmatite formation.

The field studies have resulted in two schools of thought emerging to explain the various granite-greenstone relationships that have so far been found. One group considers that all the granitic rocks present throughout the region, including the diapiric tonalitic and trondhjemitic gneisses, are intrusive into the greenstone sequences. The second group adopts the view that the tonalitic gneiss plutons are the result of tectonic processes and they would have the greenstone xenoliths representing complex infolded relics following events they would equate with the development of mantled gneiss domes (Eskola, 1948). They call on the experimental studies of Ramberg (1967, 1973) to substantiate their views and maintain that the diapirism reflects gravitational adjustments of a pre-existing ensialic basement.

At this stage it appears that the regional geological setting and the distribution of granites, greenstones and migmatites would support the ideas favoured by the first group. There is undoubted evidence for magmatic relationships in the region and the concept of "polydiapiric" intrusion of tonalitic gneisses into pre-existing greenstone material is regionally applicable. However, the detailed work has raised the possibility of alternative suggestions and it remains to be seen whether the ideas of the second group are ubiquitously applicable to the area. In all likelihood the end result of this work may ultimately incorporate pertinent ideas from both schools of thought.

* *

REFERENCES

Anhaeusser, C.R., 1974. Early Precambrian rocks in the vicinity of the Boesmanskop syenite pluton, Barberton Mountain Land, South Africa. Abs., Int. Conf. on the "Geology and Geochemistry of the Oldest Precambrian Rocks", Redwood Falls, Minnesota, 5 pp.

Anhaeusser, C.R., 1975. The Archaean granite-greenstone terrane in the vicinity of the Bosmanskop syenite pluton, Barberton Mountain Land. Abs., XVI Geokongres 1975, Geol. Soc. S. Afr., Stellenbosch, 5-7.

Anhaeusser. C.R., 1978. A geological investigation of the Archaean granite-greenstone terrane south of the Boesmanskop syenite pluton, Barberton Mountain Land. Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg (in press).

Barker, F., Friedman, I., Hunter, D.R., and Gleason, J.D., 1976. Oxygen isotopes of some trondhjemites, siliceous gneisses, and associated mafic rocks. Precambrian Res., 3 : 547-557.

Coleman, R.G., and Peterman, Z.E., 1975. Oceanic plagiogranite. J. Geophys. Res., 80(8) : 1099-1108.

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

Eskola, P.E., 1948. The problem of mantled gneiss domes. Q. J. Geol. Soc. Lond., 104 : 461-476.

Goldich, S.A., Hanson, G.N., Hallford, C.R., and Mudrey, M.G., 1972. Early Precambrian rocks in the Saganaga Lake-Northern Light Lake area, Minnesota - Ontario. Part I. Petrology and Structure. Geol. Soc. Amer. Mem., 135 : 151-177.

Hanson, G.N., and Goldich, S.S., 1972. Early Precambrian rocks in the Saganaga Lake-Northern Light Lake area, Minnesota - Ontario. Part II. Petrogenesis. Geol. Soc. Amer. Mem., 135 : 171-192.

Mackenzie, D.H., 1957. On the relationship between migration and structure in mid-Stratspey. Geol. Mag., 94(3) : 177-186.

Oosthuyzen, E.J., 1970. The geochronology of a suite of rocks from the granitic terrain surrounding the Barberton Mountain Land. Unpub. Ph.D. thesis, Univ. Witwatersrand, Johannesburg.

Prince, L.A., and Hanson, G.N., 1972. Rb-Sr isochron ages for the Giants Range Granite, northeastern Minnesota. Geol. Soc. Amer. Mem., 135 : 217-224.

Ramberg, H., 1967. Gravity, Deformation and the Earth's Crust as Studied by Centrifuged Models. Academic Press, London/New York, N.Y., 214 pp.

Ramberg, H., 1973. Model studies of gravity-controlled tectonics by the centrifuge technique. In: K.A. Dejong and R. Scholten (Editors), Gravity and Tectonics. Wiley, New York, N.Y., pp. 49-66.

Robb, L.J., 1977. A general geological description of the Archaean granitic terrane between Nelspruit and Bushbuckridge, Eastern Transvaal. Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 111 : 12 pp.

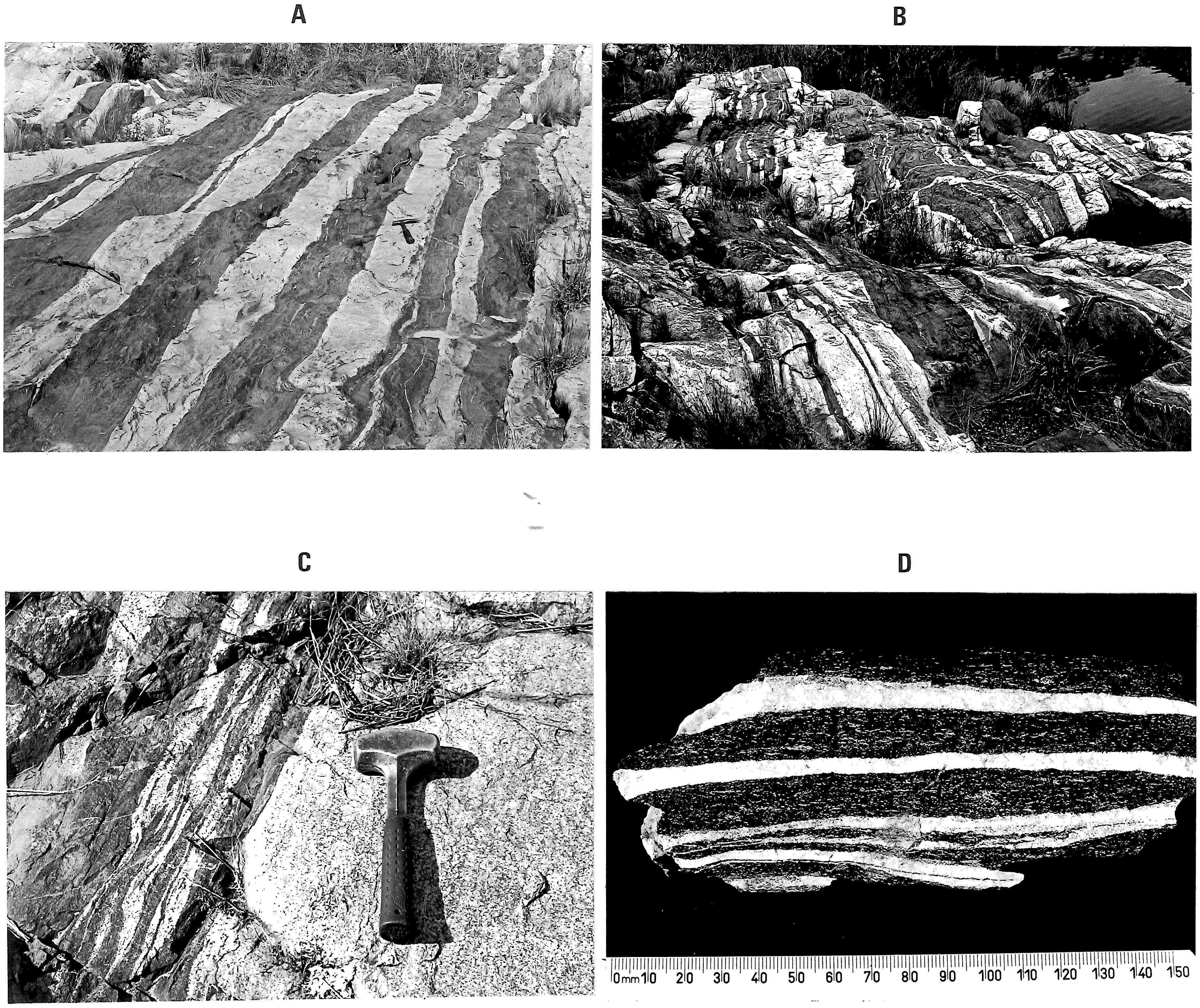
Stephansson, O., 1975. Polydiapirism of granitic rocks in the Svecofennian of central Sweden. Precambrian Res., 2 : 189-214.

Viljoen, M.J., and Viljoen, R.P., 1969. The geology and geochemistry of the Lower Ultramafic Unit of the Onverwacht Group and a proposed new class of igneous rocks. Spec. Publ. geol. Soc. S. Afr., 2 : 55-85.

Wegmann, C.E., 1929. Beispiele tektonischer Analysen des Grundgebirges in Finnland. Bull. Comm. géol. Finlande, 87 : 98-127.

* *

PLATE I



Sequence of photographs illustrating the lit-par-lit nature of granites intrusive into greenstones in the study area.

A. Alternating amphibolite bands (Barberton-type basaltic komatiites) and quartzo-feldspathic veins, Theeboom outcrop locality;

B. Alternating bands of amphibolite, trondhjemitic gneiss and quartzo-feldspathic veins in river exposures east of the Boesmanskop syenite pluton;

C. Lit-par-lit amphibolite bands at the contact of a greenstone xenolith intruded by foliated trondhjemitic gneisses in the Theespruit river west of the Boesmanskop pluton;

D. Hand-specimen showing small-scale lit-par-lit bands of hornblende amphibolite and quartzo-feldspathic veins from a locality southeast of the Theeboom outcrop.

PLATE 2

1

2

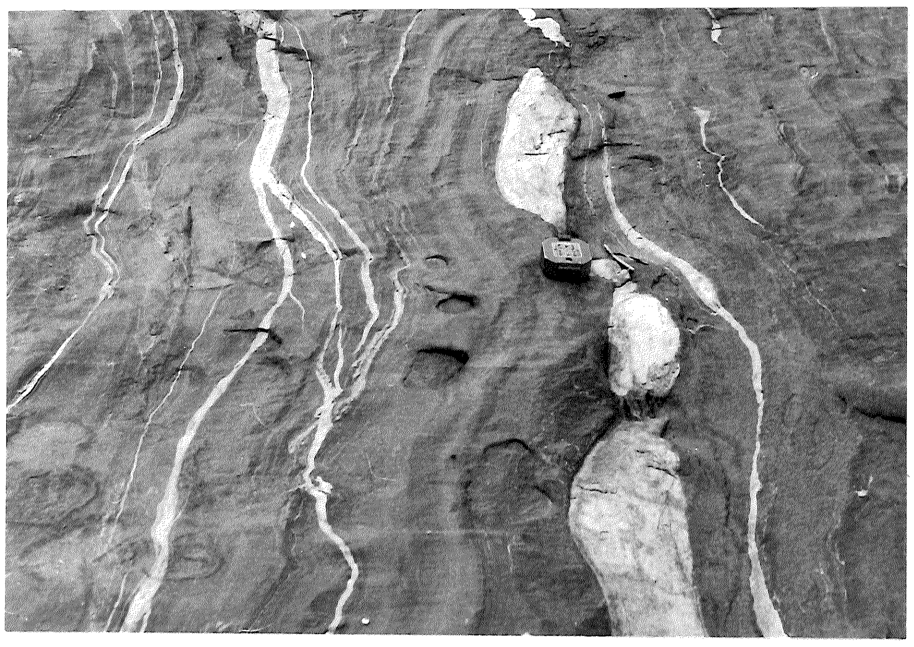
3

4

Sequence of photographs depicting various stages of migmatization of greenstone remnants in the area west of the Boesmanskop syenite pluton. The sequence shows progressive stages of migmatization, anatexis and granitization of amphibolites and other more felsic components of the greenstone xenoliths.

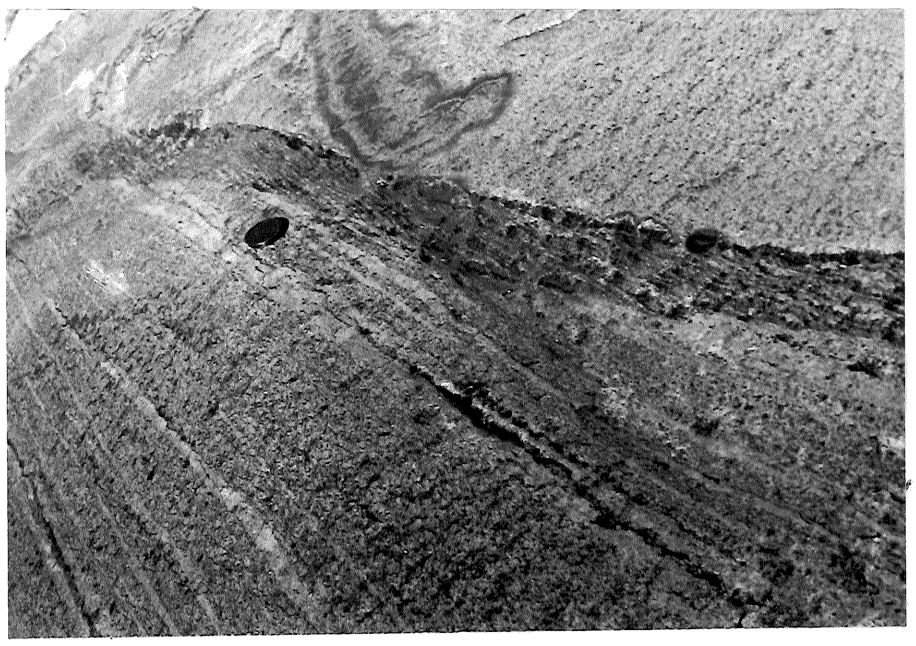
PLATE 3

A



B

C



D

Sequence of photographs from the Theeboom outcrop.

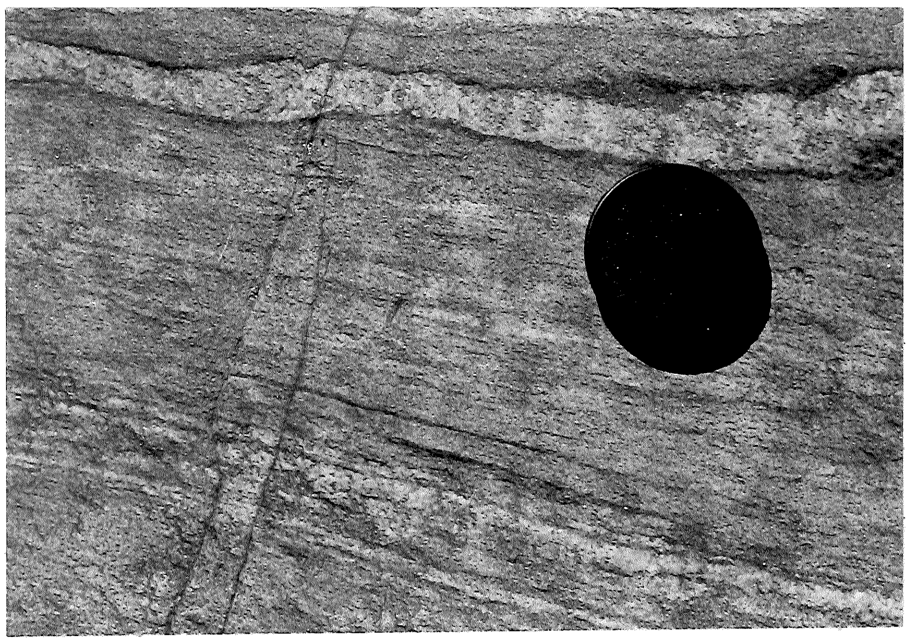
A. Photograph depicting the first stage of intrusive quartzo-feldspathic veinlets. These veinlets have been involved in deformation together with the amphibolites;

B. Photograph illustrating the relationship between the amphibolite and the foliation in the older trondhjemitic gneiss;

C. Photograph showing the well-defined contact between the younger trondhjemitic gneiss (upper portion of the photograph) and the older trondhjemitic gneiss. Discrete anatectic veinlets in the older gneiss are clearly truncated by the younger intrusive;

D. Pavement exposure at the Theeboom outcrop showing conformable bands of quartz diorite occurring within the younger trondhjemite gneiss. These bands may represent either, assimilated or granitized remnants of neighbouring amphibolitic material or, discrete intrusive dykelets in the trondhjemites.

A



B

C

D

Sequence of photographs from the Weergevonden outcrop showing progressive stages of anatexis and migmatization of a heterogeneous gneissic unit.

A. Photograph of the relatively undeformed heterogeneous gneiss of the Weergevonden outcrop. Foliation is generally linear although small-scale ptygmatic folding has taken place. Small discrete anatectic veinlets occur within a fine-grained granodioritic parent;

B. Tonalitic gneiss intruding felsic heterogeneous gneiss. Small-scale lit-par-lit relationships and anatectic veins, developed in the heterogeneous gneiss, are evident;

C. Progressive anatectic transformation of the heterogeneous gneiss resulting in the development of ptygmatically folded felsic bands;

D. Photograph of deformed heterogeneous gneiss-migmatite at the Weergevonden outcrop. Isoclinal folding is prevalent and the process of *in situ* differentiation (venitic migmatization) is greatly enhanced.