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GEOLOGICAL AND GEOCHEMICAL INVESTIGATIONS OF THE ROODEKRANS ULTRAMAFIC COMPLEX AND SURROUNDING ARCHAEAN VOLCANIC ROCKS, KRUGERSDORP DISTRICT

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by

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ABSTRACT

The geology, mineralogy and the geochemistry of the Roodekrans Greenstone Complex, situated 10 km northeast of Krugersdorp, are described, and 11 new rock analyses are presented. The successions in the area can be divided into two principal components - rocks belonging to a layered ultramafic sequence (the Roodekrans Ultramafic Complex) and rocks forming part of a succession of Mg-rich pillow basalts and subordinate peridotitic interlayers. The rocks of the layered ultramafic sequence have been serpentinized and deformed relative to the metabasalts which show signs of having been contact metamorphosed by an intrusive porphyritic granodiorite phase of the Johannesburg granite dome.

Consideration is given to the nature of the layered ultramafic sequence and chemical evidence is presented suggesting that the rocks do not constitute part of a differentiated complex but that they may rather represent an eruptive succession of ultramafic flow units like those described by Pyke et al, (1973) from Munro Township in the Abitibi greenstone belt of north-eastern Ontario or those described from the Komati Formation in the Barberton area by Viljoen and Viljoen (1969a).

The chemical data relating to the ultramafic and mafic rocks in the Roodekrans area is discussed with the aid of ternary and binary variation diagrams. The high-Mg basalts are shown to constitute a distinctive class of Archaean volcanic rock, the latter being transitional between basaltic komatiites and oceanic tholeiites. Supplementary geochemical data from the Barberton Mountain Land is combined with that of the Roodekrans area and is used to demonstrate an almost complete evolutionary trend of magma development involving olivine, orthopyroxene, and clino-pyroxene fractionation, the latter process being responsible for the generation of a wide range of cumulus-enriched liquids and melt composites ranging from dunites, orthopyroxenites, websterites, and gabbroic igneous rocks to peridotitic and basaltic komatiites, high-Mg basalts and oceanic tholeiites.

Finally, it is suggested that the generation of the ultramafic-mafic assemblages, like those found in the basal units of the southern Africa greenstone belts, occurred as a result of unique P-T conditions in the Archaean. These distinctive geotectonic conditions have only rarely been simulated in post-Archaean times.

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GEOLOGICAL AND GEOCHEMICAL INVESTIGATIONS OF THE ROODEKRANS ULTRAMAFIC COMPLEX AND SURROUNDING ARCHAEAN VOLCANIC ROCKS, KRUGERSDORP DISTRICT

I. INTRODUCTION

In South Africa rocks forming part of the Archaean granite-greenstone basement are mainly exposed in the eastern Transvaal Lowveld and in the far northern Transvaal. In the southern and western Transvaal outcrops of similar rocks are confined to a few domical granite masses that occur as inliers beneath the younger cover sequences (Figure 1). The granite dome situated north of Johannesburg has numerous greenstone remnants scattered widely throughout its 700 square kilometre expanse (Anhaeusser, 1973a). The most extensive of these occurs in the southwestern and western portions of the dome near Muldersdrif, in the Krugersdorp District. In most areas across the

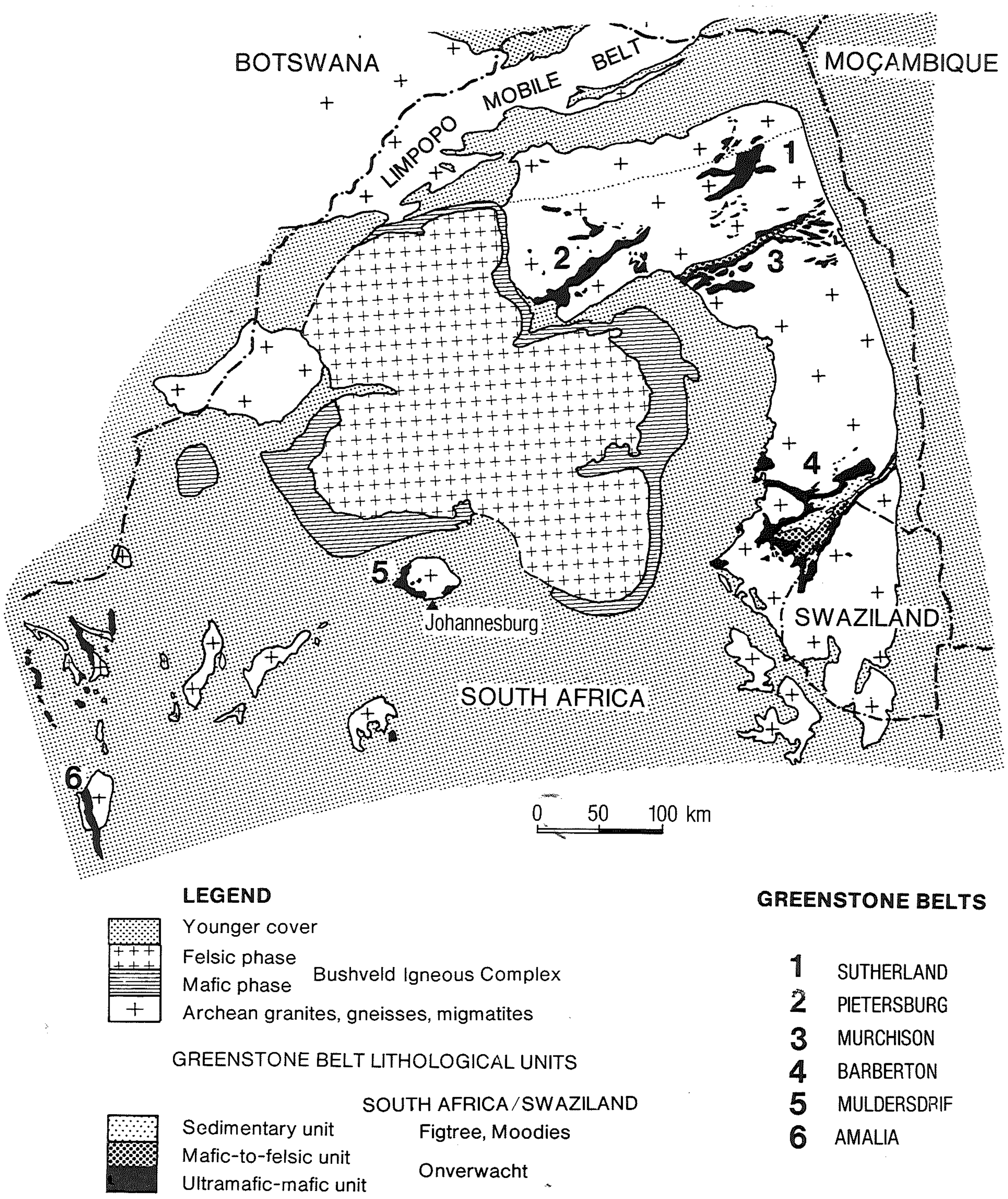

Figure 1 : Geological map of the Kaapvaal craton showing the exposed areas of the Archaean granite-greenstone terrane

dome the greenstone remnants are either poorly exposed or are within city limits and detailed mapping is generally no longer feasible. A few areas, however, have been singled out for special study, two of which occur in the western segment mentioned above. The first of these is referred to as the Muldersdrif Ultramafic Complex and is located approximately 10 km north of Krugersdorp (Figure 2). The second area, located immediately south of Muldersdrif, is best developed on the farm Roodekrans 183IQ and is referred to as the Roodekrans Greenstone Complex.

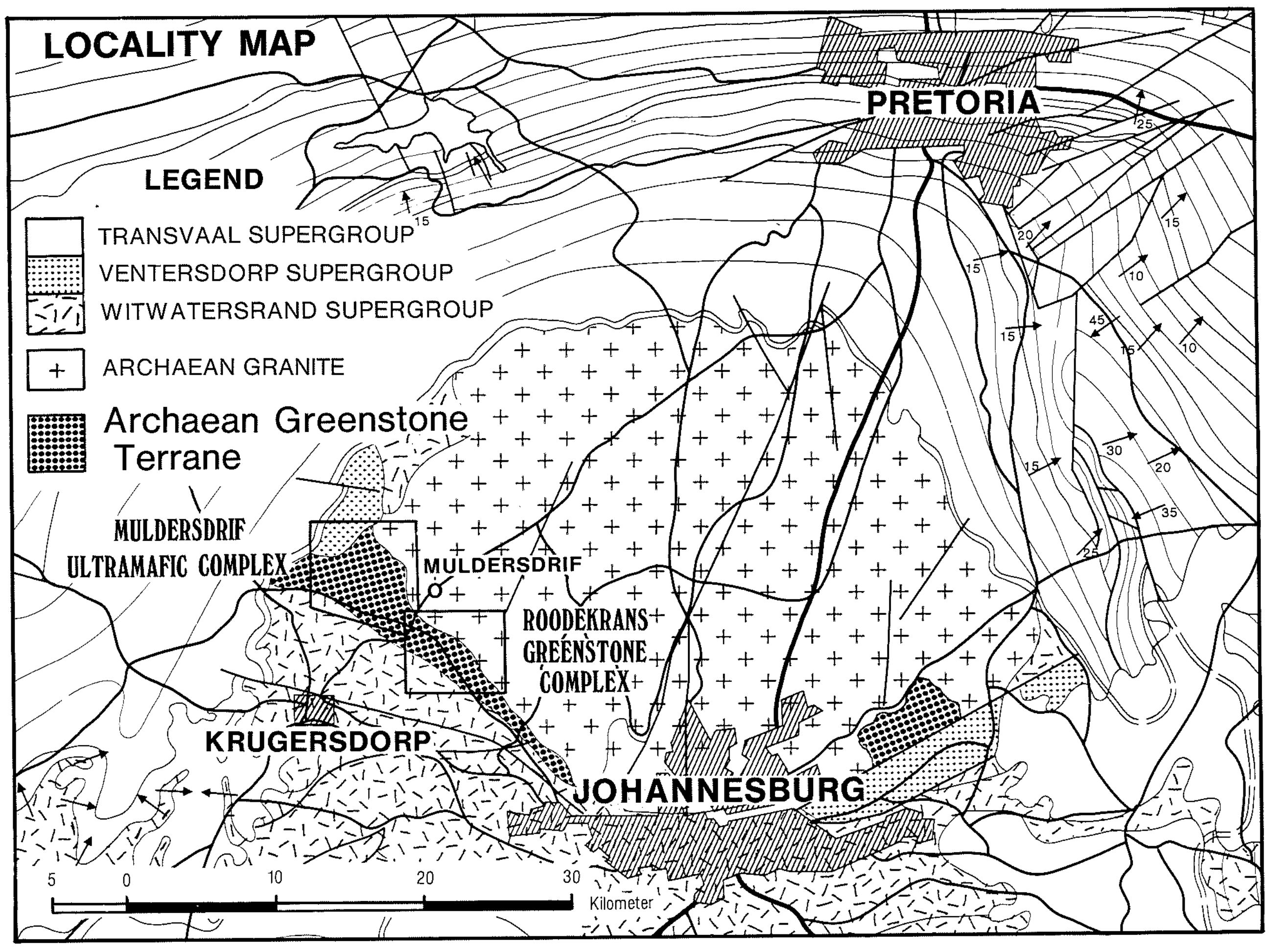

Figure 2 : Locality map showing the Johannesburg granite dome and the Archaean greenstone remnants in the Roodekrans-Muldersdrif areas

The earliest references to rocks older than the Witwatersrand succession north of Krugersdorp were made by Hall (1906) and Kynaston (1907a, b). These authors described a variety of ultrabasic, basic, and acid schists, which they correlated with the Swaziland System (now Supergroup), but did not produce any detailed maps of the area. Later Mellor (1917, 1921) showed the generalized extent of the Swaziland successions on his geological maps of the Witwatersrand and country surrounding Johannesburg. In 1933 Willemse undertook studies on the Johannesburg-Pretoria granite and made only cursory mention of the Archaean greenstones which he regarded as undoubtedly pre-granite in age. The first attempt at mapping some of the greenstone terrane was that carried out by Hendriks (1961), who produced a 1:50 000 scale compilation of the area between Krugersdorp and the most northerly outlier of the Witwatersrand successions on the farm Zwartkop 525JQ (Figure 2).

The writer first became interested in the Archaean rocks of the Johannesburg dome in 1971, and again in 1973 published an account of the geology and geochemistry of a wide range of granites and gneisses dated by Allsopp (1961) as being 3 200 m.y. old. In 1972 a systematic programme involving the detailed mapping of selected greenstone remnants, was initiated. Preliminary accounts of the geology of the Muldersdrif Ultramafic Complex and the Roodekrans greenstone remnant were made available (Anhaeusser, 1973b; 1974), and aspects relating to the chrysotile asbestos mineralization of the area were briefly described (Anhaeusser, 1976).

The report which follows deals essentially with the geology of the Roodekrans area. This is to be followed later by a comprehensive account of the Muldersdrif Ultramafic Complex (Anhaeusser, in preparation). The rocks of these two areas are genetically linked but to facilitate description have been handled separately. It is the purpose of this paper to describe the nature and geochemistry of the Archaean ultramafic and mafic successions in the Roodekrans area and to emphasize, in particular, a class of high magnesium pillow basalts that appear to be transitional between komatiite varieties and other reported classes of Archaean basalts.

Although some of the successions in the area have been severely affected structurally, detailed mapping established the presence of a well-layered sequence of ultramafic rocks, the latter being referred to as the Roodekrans Ultramafic Complex in Figure 3. Evidence of a volcanic versus plutonic origin for these rocks is discussed, and comparisons are made with what are believed to be analogous sequences from Munro Township, Ontario, Canada (Pyke et al., 1973), and the Komati Formation in the Barberton Mountain Land (Viljoen and Viljoen, 1969a).

Polybaric fractionation of olivine and to a lesser extent orthopyroxene from initially formed peridotitic liquids of the type reported in the Sandspruit Formation of the Barberton Mountain Land (Viljoen and Viljoen, 1969b) has been considered as the main factor in the evolution of associated rocks of lower magnesia content (McIver and Lenthall, 1974; McIver, 1975). The chemical data from the Roodekrans area, supplemented by data from the mafic and ultramafic volcanic and plutonic rocks in the Nelshoogte Schist Belt and the Stolzburg layered differentiated body in the Barberton area, is examined with the aid of ternary and binary variation diagrams. Confirmation of some of McIver's (1975) findings are made but, in addition, it is suggested that clinopyroxene fractionation has also played a prominent role in the evolution of the various basaltic komatiites, high-Mg basalts, and primitive oceanic-type tholeiites.

II. GENERAL GEOLOGY

The region investigated occurs immediately north of, and underlies, the prominently outcropping ridges of Lower Witwatersrand strata developed between Krugersdorp and Johannesburg (Plate 1A).

(a) Granites

Granitic rocks intrude the greenstone remnant along the northern contact and consist of homogeneous, medium- to coarse-grained porphyritic granodiorites (Plate 1B). Rocks of this type were shown by Anhaeusser (1973a) to occupy extensive areas of the southwestern quadrant of the Johannesburg dome. The porphyritic granodiorites, chemical analyses of which are provided in Table 1, were considered by Anhaeusser to represent one of the latest granite events on the Johannesburg dome, a fact being borne out so far by preliminary U-Pb isotopic age determination studies (A.J. Burger, personal communication, 1975).

Granodiorites of this type in juxtaposition with Archaean greenstone remnants are somewhat unusual, but not unknown, in the granite greenstone terrane of southern Africa. More often the granitic rocks flanking the volcanic belts comprise diapiric tonalitic or trondhjemitic gneisses, the latter frequently containing aligned xenoliths in strongly foliated contact zones (Anhaeusser et al., 1969; Viljoen and Viljoen, 1969c). Furthermore, the tonalitic gneisses are invariably responsible for the development of prominent schistosity in the metavolcanic rocks bordering the granites. In the Roodekrans area the metabasalts appear to be relatively undeformed in all but a few areas. In the eastern portion of the map area (Figure 3, B2) steeply dipping metabasalts containing flattened amygdales and vesicles occur near the granite contact (Plate 1C) but more commonly it was found that the lavas still retain many of their original volcanic textures and structures. In Plate 1D undeformed amygdaloidal basalts are illustrated, the latter rocks occurring at sample locality R018 in close proximity to the granitic contact (Figure 3, A2). Also near this locality pillow lavas are exposed which, like the amygdaloidal basalts, are relatively undeformed and show perfectly preserved radial pipe amygdales, the latter orientated perpendicular to the outer pillow margins (Plate 1E).

(b) Metabasalts

As is shown on the geological map, outcrops of the metabasalts are generally poor. The most continuous exposure is available along the valley slopes east of the stream known as Muldersdrifseloop which drains northwards across the map area (Figure 3, A1 and B1). Most of the basalts appear to be hornfelses, suggesting that the porphyritic granodiorite may have been responsible for contact metamorphism of the basalts. The hornfelsic metabasalts commonly display anastomosing quartz vein networks (Plate 1F) but localities were found where rocks free of this phenomenon could be sampled.

As has already been mentioned pillow structures were observed in a number of localities throughout the area and these, together with sites where amygdales and vesicles are still evident, are shown on the accompanying geological map of the area (Figure 3). The pillow lavas found in the Roodekrans area are the first recorded in any of the Archaean greenstone remnants on the Johannesburg dome. The writer has also found pillow lavas, the latter containing spherulites and ocelli structures, in the adjoining map area, south of the Muldersdrif Ultramafic Complex. Some of the best preserved pillow basalts occur south of the main road (Figure 3, A1) near sample locality R021. Here, variably sized, rounded (Plate 2A), and irregular-shaped pillows (Plate 2B) occur interlayered with a thin

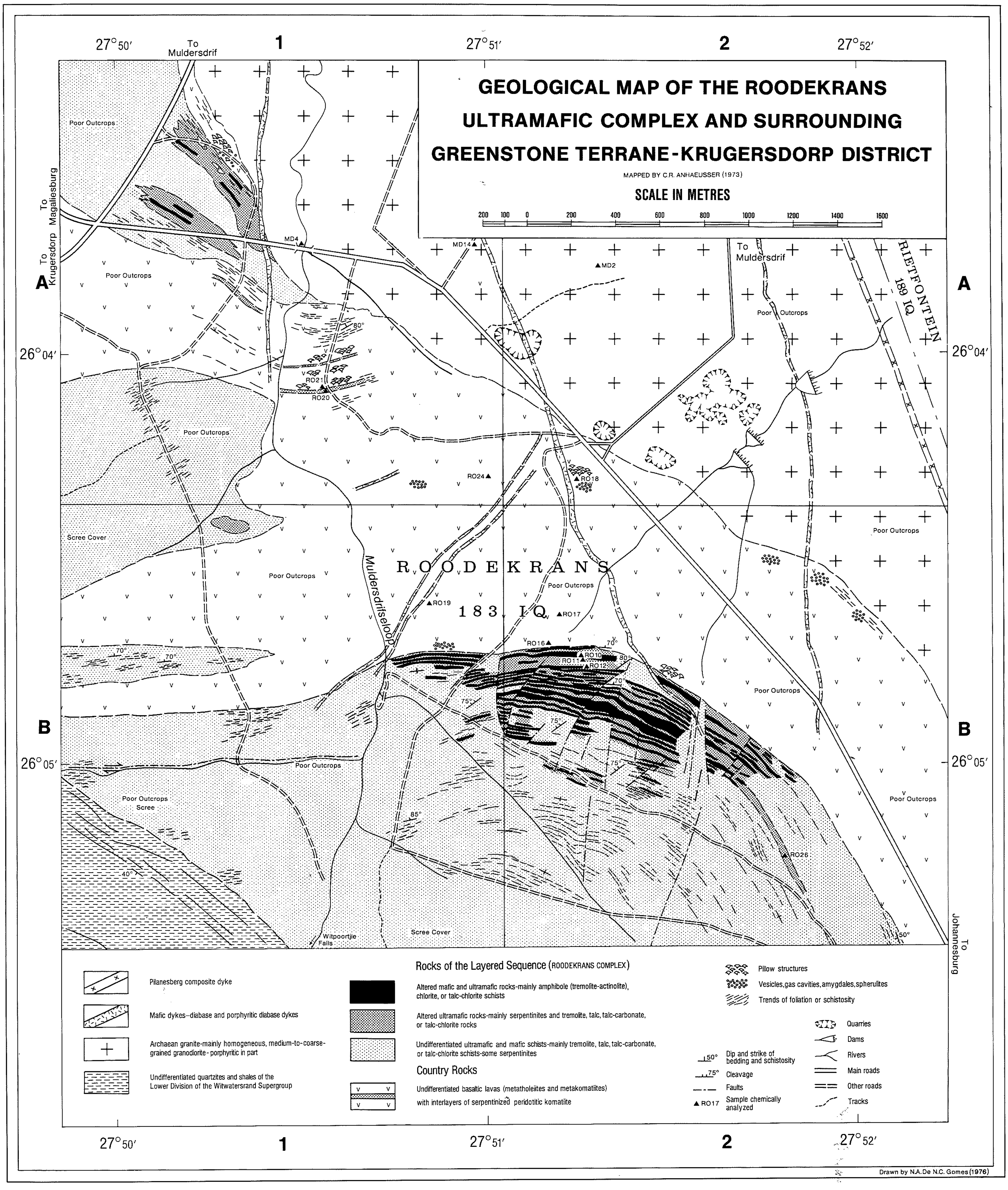

Figure 3 : Geological map of the Roodekrans Ultramafic Complex and surrounding greenstone terrane - Krugersdorp District.

serpentinized ultramafic unit, the latter considered to be of subaqueous extrusive origin. Plate 2B, which illustrates a dumb-bell-shaped pillow in the metabasalts, also shows thin chilled pillow selvedges and a tricuspate void filled with interpillow breccia and quartz and carbonate.

The metabasalts are dark greenish-black in colour on fresh surfaces and weather to produce a deep reddish-brown soil. Mineralogically the rocks consist mainly of tremolite and actinolite with variable amounts of Mg-rich chlorite (showing anomalous grey-brown pleochroism), quartz, untwinned plagioclase feldspar (albite), epidote, and clinozoisite. The amphiboles, which are generally iron-poor, colourless, or pale yellow-green actinolites, occur as a decussate interlocking network of tabular to bladed and acicular crystals. Quartz and untwinned plagioclase occurs as a matrix mosaic, the latter mineral commonly altered to epidote or clinozoisite. The rocks are generally medium- to fine-grained and under the microscope show well-defined crystal outlines and mineral separations indicative of contact metamorphic textures.

The interlayered ultramafic extrusives consist mainly of antigorite, bladed and fibrous tremolite, chlorite with anomalous grey interference colours, and scattered particles and veinlets of magnetite. The original texture and mineralogy of these rocks has been destroyed by the serpentinization of the ultramafic layers.

The mineralogy of the Roodekrans metabasalts is indicative of the stability range of *greenschists* or *greenstones*, the latter developing in what Winkler (1974) regards as the low-grade, lower temperature part of the mafic greenschist assemblage. This is characterised by the albite-actinolite-chlorite zone where temperatures less than 500°C prevail at low pressures (< 4 Kb).

(c) The Roodekrans Complex

South of the metabasaltic lava zone is a sequence of layered ultramafic rocks consisting essentially of alternating serpentinite and amphibolite units. This sequence, the layered nature of which can best be seen in the southeastern quadrant of the map area (Figure 3, B2), extends southwards and, before disappearing beneath the quartzites and shales of the Lower Division of the Witwatersrand Supergroup, is covered by a wide talus slope.

By contrast with the metabasalts the ultramafic rocks are generally severely altered by a variety of tremolite-chlorite-talc-carbonate schists, the latter interlayered with serpentinites in the central part of the map area. The main mass of ultramafic schists defines a broad arcuate flexure, concave to the south, and extending beneath the Witwatersrand cover sequences with a pronounced angular unconformity (Figure 3, B1). The ultramafic schists are generally vertical to steeply inclined (Plate 2C) and are further complicated by a superimposed northeast-trending cleavage which again is best seen in the central part of the layered sequence. The cleavage dips to the northwest at a consistent angle of approximately 75°. Numerous north- or northeast-trending faults divide the central layered sequence into triangular and sub-rectangular segments and it is possible that the cleavage is related to this fracture system.

The Roodekrans fractures may, themselves, be linked with the tectonic development of the West Rand Syncline. In the area northeast of Krugersdorp, structural mapping by Roering (1968) revealed that a prominent flexure in the outcrop distribution of the arenaceous members of the Lower Division of the Witwatersrand succession was caused by marked east-west-trending right lateral faulting. One such fault appears to project into the underlying schists (Figure 3, B1) and this, together with other faults in the area, may have resulted in the development of second-order fracturing and cleavage in the relatively incompetent layered ultramafic successions of the Roodekrans Complex.

Where the rocks of the layered succession are still relatively intact, massive serpentinite units alternate with tremolite-chlorite units. The cyclical repetition of these two component rock units is more frequent than that depicted on the geological map of the area. Poor continuity of exposure, however, makes it difficult to refine, or resolve further, the geology of the area.

Mineralogically the serpentinites consist of antigorite, tremolite, chlorite, talc, magnetite, and in some places carbonate. Antigorite predominates and distinguishes these rocks from the amphibolite interlayers which contain mainly tremolite and Mg-rich chlorites. Only accessory amounts of magnetite occur in the amphibolitic rocks but talc and carbonate is prominent in some units, being responsible for the nodular buff-coloured blebs and lenses seen in places (Plate 2D). In neither of the two main rock types of the complex were primary mineral phases noted.

(d) Other Ultramafic Rocks

In the western part of the map area, discontinuous and poorly exposed outcrops of ultramafic schists and massive serpentinites occur as lensoid bodies in the metabasalts. In the northwest, serpentinites and ultramafic schists extend westwards across the Krugersdorp-Pretoria highway to link with the Muldersdrif Ultramafic Complex, but are also poorly exposed.

(e) Dykes

A number of mafic dykes occur in the area. Most of these are medium-grained diabase or porphyritic diabase dykes that strike in a NW or NE direction across the trends in the greenstone remnant and extend into the granites in the north. Attempts made to date these dykes using K-Ar methods failed (P.M. Hurley, written communication, 1974), but they are thought likely to belong to a phase of activity associated with the emplacement of the Bushveld Igneous Complex dated at 1 950 m.y. by Nicolaysen (1962).

A Pilanesberg composite dyke consisting of diabasic and syenitic rock types extends through the northeastern part of the map area (Figure 3, A2) but is poorly exposed. The best development of the dyke occurs to the northwest where it has been traced well-beyond Muldersdrif (Anhaeusser, 1973a). The Pilanesberg dykes have been dated at approximately 1 300 m.y. (Schreiner and Van Niekerk, 1958; Van Niekerk, 1962).

III. GEOCHEMISTRY OF THE ULTRAMAFIC-MAFIC ASSEMBLAGES

(a) Introduction

From field observations alone it was impossible to establish whether or not the Roodekrans layered ultramafic sequence represents an original differentiated complex like that of the Muldersdrif body to the northwest, or like those reported from the Barberton greenstone belt (Anhaeusser, 1969; 1976; Viljoen and Viljoen, 1969d). Petrological examination of the rocks likewise proved of little help as the serpentinization process, coupled with tectonic overprinting, has completely destroyed signs (if any existed) of cumulate textures. The geochemical approach, while in no way being diagnostic, did nevertheless provide some clues as to the probable nature of the layered sequence and is discussed below.

Geochemical data pertaining to the eruptive greenstone successions north of the Roodekrans Complex has revealed that the rocks are high-Mg basalts and peridotites not unlike those coexisting with the komatiitic volcanic rocks in the lower formations of other southern African greenstone belts (Anhaeusser, 1972; Grobler, 1972; Minnitt, 1975; Viljoen and Viljoen, 1969b; Viljoen et al., 1976 - in press; and M. Prinsloo, personal communication, 1976).

(b) Chemistry of the Roodekrans Layered Sequence

Analyses, CIPW norms, and colour indices of samples from the Roodekrans Complex are listed in Table 1 (columns 1-4). As can be seen, the samples of serpentinite are appreciably richer in MgO and poorer in SiO_2, Al_2O_3, CaO, and Na_2O, than the interlayered amphibolitic ultramafic rocks. It can also be seen in Table 1 that the amphibolitic rocks contain appreciable amounts of normative enstatite and plagioclase while these minerals have not been observed in thin section. Pyke et al (1973) found, in rocks of a similar character and composition from Munro Township, Ontario (Table 2), that the pyroxene was diopsidic augite with an unusually high Al_2O_3 content (8,5 wt per cent). Similar high Al_2O_3 contents (6,5 wt per cent) in pyroxenes from spinifex textured ultramafic rocks from the Western Australian Archaean have been reported by Nesbitt (1971). Although no comparable analyses are possible from the amphibolitic ultramafics of the Roodekrans Complex it is suggested, by analogy, that high-alumina clinopyroxenes may well have been present. These would have enabled the calcium that would otherwise be tied up as anorthite to be free to convert enstatite to diopside, an explanation offered by Pyke et al. (1973) to explain the anomalous normative hypersthene and plagioclase in the Munro Township ultramafic rocks.

In attempting to establish the nature of the Roodekrans Complex the factors supporting an intrusive differentiated origin versus an eruptive origin for the layered sequence were evaluated. The alternating, or cyclical, layering seen in the Roodekrans body is not unlike that recorded in many of the layered differentiated bodies in the Barberton greenstone belt (Anhaeusser, 1976) although it is usual to find in these, as well as in the nearby Muldersdrif Ultramafic Complex, several features which appear to be diagnostic of an intrusive differentiated origin. These include signs of cumulate textures (usually recognizable even in altered bodies), chrysotile asbestos fibre development (invariably linked with folded and faulted olivine cumulate rocks), and cyclically repetitive units of dunite, orthopyroxenite, clinopyroxenite, and gabbro.

The lithological and chemical variations encountered in the Roodekrans Complex do not support an obvious correlation with layered differentiated assemblages. An alternative might be to consider the Roodekrans sequence as representing a pile of ultramafic flow units similar to those described from northeastern Ontario, Canada, the Yilgarn Block of Western Australia, and the Barberton Mountain Land, South Africa. In the latter region Viljoen and Viljoen (1969a) described a number of broad ultramafic zones which, they maintained, were formed by the subaqueous extrusion of successive flows of a mobile liquid magma of peridotitic composition. Pyke et al. (1973) described a similar sequence in the Munro Township area where a unique occurrence within the Abitibi greenstone belt provides clear exposures of approximately 60 ultramafic flow units developed over a

TABLE 1

CHEMICAL ANALYSES, C.I.P.W. NORMS, AND COLOUR INDECES OF VARIOUS ROCK TYPES ASSOCIATED WITH THE ROODEKRANS GREENSTONE REMNANT

	Ultramafic Rocks - Roodekrans Complex				Peridotite	High Mg-Basalts						Porphyritic Granodiorites		
	1*	2*	3^{ϕ}	4^{ϕ}	5*	6*	7*	8*	9*	10*	11*	12†	13†	14†
	RO 11	RO 26	RO 10	RO 12	RO 20	RO 18	RO 17	RO 24	RO 16	RO 19	RO 21	MD 4	MD 14	MD 2
SiO_2	35,69	35,74	46,20	49,30	41,78	49,84	50,25	50,47	51,32	51,74	52,98	72,26		
TiO_2	0,07	0,06	0,15	0,16	0,22	0,39	0,30	0,40	0,28	0,31	0,53	0,23		
Al_2O_3	2,77	2,04	6,40	7,10	5,06	15,76	15,85	15,22	15,22	15,35	11,25	14,42		
Fe_2O_3	10,52	2,89	6,50	7,60	5,28	2,32	0,64	0,79	0,62	0,72	1,00	0,49		
FeO	0,86	2,91	-	-	4,53	5,39	6,51	7,47	6,63	6,36	7,91	1,11		
MnO	0,12	0,13	0,17	0,19	0,13	0,22	0,16	0,19	0,16	0,16	0,18	0,04		
MgO	34,39	37,14	28,40	22,40	29,69	7,20	10,63	9,09	10,92	9,47	8,37	0,33		
CaO	2,45	1,32	5,27	9,30	3,95	14,99	12,04	12,48	10,13	11,78	12,65	1,62		
Na_2O	0,06	0,09	0,20	0,50	0,12	1,89	1,15	1,69	1,17	1,26	2,26	4,34	4,45	4,71
K_2O	0,05	0,02	0,01	0,05	0,03	0,06	0,05	0,10	0,06	0,06	0,29	4,02	3.95	3,78
P_2O_5	0,02	0,02	0,03	0,02	0,03	0,08	0,07	0,08	0,07	0,07	0,10	0,06		
H_2O^+	10,29	10,35	5,70	3,20	0,13	1,36	1,91	1,43	2,85	1,86	1,54	0,80		
H_2O^-	0,20	0,13	0,19	0,22	8,52	0,09	0,12	0,07	0,07	0,10	0,08	0,01		
CO_2	2,05	6,04	0,10	-	0,05	0,28	0,05	0,05	0,12	0,12	0,20	0,15		
S	-	-	-	-	0,0074	0,0109	0,0035	0,0047	0,0020	0,0074	0,0020	-		
Cr_2O_3	0,27	0,24	-	-	0,49	0,05	0,08	0,06	0,07	0,06	0,10	-		
Sr ppm	17	8	-	-	19	73	27	51	40	41	207	283	251	232
Rb ppm	11	9	-	-	4	12	8	11	16	9	22	292	331	340
Totals	99,81	99,12	99,32	100,04	100,02	99,93	99,81	99,60	99,69	99,43	99,44	99,88		

Modal Compositions (C.I.P.W. weight norms)

	1*	2*	3^{ϕ}	4^{ϕ}	5*	6*	7*	8*	9*	10*	11*	12†	13†	14†
Cc	-	-	0,48	-	0,25	1,28	0,23	0,23	0,56	0,56	0,92	0,69		
Ap	0,05	0,06	0,07	0,05	0,08	0,19	0,17	0,19	0,17	0,17	0,24	0,14		
Il	0,15	0,13	0,30	0,31	0,46	0,75	0,58	0,77	0,55	0,60	1,02	0,44		
Or	0,34	0,14	0,06	0,31	0,20	0,36	0,30	0,60	0,36	0,36	1,74	23,89		
Ab	0,58	0,93	1,80	4,37	1,12	16,12	9,90	14,50	10,15	10,85	19,40	36,92		
An	3,21	6,20	17,61	17,51	14,47	34,60	38,58	34,10	36,99	36,68	19,98	6,73		
Mt	3,40	5,09	2,53	1,63	8,40	3,39	0,94	1,16	0,92	1,06	1,47	0,71		
Di	4,37	1,21	6,73	20,22	4,85	22,27	12,58	15,14	7,81	12,36	21,94	-		
He	-	0,04	0,63	3,52	0,22	8,39	4,65	7,44	2,88	5,05	12,08	-		
Q	-	-	-	-	-	1,39	1,51	0,45	4,49	4,97	2,90	27,76		
Fo	54,59	66,84	22,69	12,30	29,67	-	-	-	-	-	-	-		
Fa	-	2,47	2,70	2,71	1,70	-	-	-	-	-	-	-		
Fs	-	0,58	4,56	6,49	2,01	3,55	9,49	9,52	10,87	9,08	7,34	1,42		
En	18,66	16,33	39,82	30,61	36,58	7,74	21,09	15,92	24,25	18,26	10,97	0,83		
C	-	-	-	-	-	-	-	-	-	-	-	0,47		

Colour Index

	1*	2*	3^{ϕ}	4^{ϕ}	5*	6*	7*	8*	9*	10*	11*	12†	13†	14†
	78	88	80	78	84	46	49	49	47	46	54			

Analysts :
* * General Superintendence Company Limited
* ϕ Bergström and Bakker
* † National Institute for Metallurgy
* Sulphur analyses by A.J. Naldrett, University of Toronto, Ontario, Canada.

Columns :
* 1 and 2 Serpentinized ultramafic rocks (dunite, periodotite) Roodekrans Complex.
* 3 and 4 Tremolite-chlorite rocks (picrites or Geluk-type basaltic komatiites), Roodekrans Complex.
* 5 Serpentinized peridotite flow interlayered with pillow basalts, Roodekrans greenstone remnant.
* 6 - 11 High Mg-basalts (metatholeiites, metakomatiites), Roodekrans greenstone remnant.
* 12 - 14 Homogeneous, medium-coarse porphyritic granodiorites (after Anhaeusser, 1971 and 1973).

TABLE 2

ANALYSES OF ARCHAEAN ULTRAMAFIC FLOW UNITS AND SIMILAR ROCK TYPES FROM MUNRO TOWNSHIP (ONTARIO), THE BARBERTON MOUNTAIN LAND (SOUTH AFRICA), SKYE (SCOTLAND), AND UBEKENDT EJLAND (WEST GREENLAND)

	MUNRO TOWNSHIP, ONTARIO			KOMATI FORMATION BARBERTON MOUNTAIN LAND			PICRITES AND HIGH-Mg KOMATIITES		
	1	2	3	4	5	6	7	8	9
SiO_2	39,30	41,00	40,80	40,36	42,67	41,58	44,32	43,57	47,37
TiO_2	0,17	0,21	0,25	0,41	0,30	0,38	0,78	0,58	0,46
Al_2O_3	5,91	5,54	10,00	1,97	3,33	3,44	10,29	10,29	6,79
Fe_2O_3	3,68	3,46	2,94	5,84	6,28	5,20	1,88	3,77	1,18
FeO	3,31	6,61	6,49	3,75	4,74	6,01	8,93	6,50	8,08
MnO	0,10	0,13	0,16	n.d.	0,19	0,19	0,11	0,14	0,19
MgO	33,90	32,00	23,30	35,17	29,03	26,71	22,07	20,99	20,39
CaO	2,58	4,21	6,86	3,45	4,49	5,99	8,06	7,47	8,31
Na_2O	0,20	0,28	0,23	0,05	0,28	0,12	0,94	1,01	0,39
K_2O	0,12	0,07	0,07	0,0	0,05	0,03	0,10	0,04	0,06
P_2O_5	0,03	0,01	0,02	n.d.	n.d.	n.d.	0,12	0,03	0,05
H_2O^+	9,23	5,47	5,91	7,76	7,04	9,03	1,41	4,84	5,26
H_2O^-	1,06	0,73	0,86	0,21	0,24	0,18	0,92	0,40	0,25
CO_2	0,31	0,42	0,28	n.d.	0,36	n.d.	0,15	n.d.	n.d.
Cr_2O_3	0,29	0,38	0,45	n.d.	0,38	0,30	n.d.	n.d.	n.d.
Totals	100,19	100,07	98,62	99,38	99,76	99,55	100,08	99,63	

Modal Compositions (C.I.P.W. weight norms)

Cc	1,56	2,02	1,38	-	1,77	-	0,70	-	-
Ap	0,08	0,02	0,05	-	-	-	0,28	0,07	0,12
Il	0,36	0,42	0,51	0,86	0,61	0,80	1,51	1,17	0,93
Or	0,78	0,44	0,45	-	0,32	0,20	0,60	0,25	0,38
Ab	1,87	2,50	2,11	0,47	2,56	1,13	8,10	9,04	3,52
An	11,76	14,41	28,18	5,66	8,28	9,75	23,98	24,78	17,70
Mt	5,90	5,30	4,61	9,30	9,81	8,40	2,77	5,78	1,82
Di	-	3,48	4,66	10,11	10,14	16,91	9,77	9,89	16,78
He	-	0,26	0,53	0,14	0,22	1,43	2,13	1,34	3,88
Fo	46,47	43,06	26,57	45,22	22,83	25,00	28,11	23,17	8,44
Fa	1,06	4,04	3,80	0,79	0,63	2,68	7,76	3,97	2,47
Fs	0,59	1,90	3,12	0,45	1,08	3,15	3,00	2,91	9,64
En	26,98	21,05	22,70	27,01	40,63	30,55	11,29	17,63	34,31

Colour Index

	81	79	66	93	85	88	65	65	77

Columns : 1-3 Ultramafic flow unit, Munro Township, Ontario (Pyke et al., 1973). 1. Knobby peridotite near base of flow, 2. medium- to fine-grained peridotite, lower part of flow unit, 3. spinifex peridotite, upper part of flow unit.

4-6 Ultramafic flow unit, Barberton Mountain Land (Viljoen and Viljoen, 1969a). 1. Base of peridotite flow, 2. centre of peridotite flow, 3. top of peridotite flow.

7 Picrite, Ubekendt Ejland, West Greenland (quoted from Drever and Johnston, 1967).

8 Picrite, Skye, Scotland (quoted from Drever and Johnston, 1967).

9 Geluk type komatiitic basalt, Komati Formation, Barberton area (Viljoen and Viljoen, 1969b).

stratigraphic thickness of 125 m. The excellence of exposure in this area has enabled individual flow units, ranging in thickness from 0,5 to 15 m (average 3 m), to be recognized and studied in detail.

A typical flow unit as described by Pyke et al. (1973) is made up of two parts. The lower part consists of knobby and medium- to fine-grained peridotites, overlain by foliated, elongated skeletal olivine crystals. The upper part of the flow contains a spinifex zone wherein are developed criss-crossing sheafs or bladed crystals of olivine (crystalline quench structures), the latter capped by a chilled and fractured flow top.

Chemical analyses from the lower and upper parts of the flows are listed in Table 2. Also in this table is a comparable set of data from the base, centre, and top of an ultramafic flow unit from the Komati Formation in the Barberton area, described by Viljoen and Viljoen (1969a). Comparison of the Canadian and Barberton chemistry with that of the Roodekrans Complex (Table 1, columns 1-4) shows a high degree of similarity. This is particularly evident in the decrease upwards, in the flow units, of MgO and a corresponding increase of most other components, especially CaO and Al_2O_3.

The spinifex zone from Munro Township (Table 2, column 3) contains 30,3 per cent normative plagioclase, and 30,4 per cent normative olivine and, as pointed out by Pyke et al. (1973), is not ultramafic *sensu stricto* but is picritic (cp. Table 2, columns 7, 8). A better case can be made for regarding the liquid portion of the Barberton komatiite flows as ultramafic. In Table 2, column 6, a pillowed peridotite from the top of a flow unit contains only 10,9 per cent normative plagioclase and, with a colour index of 88, clearly passes as ultramafic rock (Wyllie, 1967).

Many ultramafic rocks grade into mafic rocks by an increase in plagioclase feldspar. Modally no plagioclase or pyroxene is evident in the Roodekrans rocks but the amphibolitic layers contain 19,4 and 21,9 per cent normative plagioclase, 25,4 and 15,0 per cent normative olivine and 39,8 and 30,6 per cent normative enstatite. They therefore have less plagioclase than the Barberton peridotite liquids and appear to be transitional in composition between ultramafic and picritic. This is also borne out by colour index comparisons.

One of the Roodekrans amphibolite interlayers (Table 1, column 4) has a composition very similar to Geluk type komatiites, an average analysis of which is listed in Table 2, column 9, for comparison. Both the normative compositions and the colour indices of these rocks also compare favourably.

The rocks of the Roodekrans Complex are, in the light of the available evidence, considered to be analogous to the eruptive ultramafic flow sequences reported in Canada and in the Barberton area.

(c) Chemistry of the Metabasaltic and Metaperidotitic Eruptives

One peridotite and six metabasalt samples were selected for chemical analysis, the results of which are listed in Table 1, columns 5-11. The peridotite, which is serpentinized, occurs interlayered with pillow basalts (Figure 3, A1) and has a composition similar to the peridotitic komatiites reported from the lower stratigraphic divisions of most southern African greenstone belts (Anhaeusser, 1972; Grobler, 1972; Viljoen and Viljoen, 1969a, b).

The mafic volcanics consist mainly of Mg-rich metatholeiites and metakomatiites, the latter being analogous to some of the Barberton-type komatiites described by Viljoen and Viljoen (1969b) from the southern part of the Barberton greenstone belt. The high-Mg basalts from the Roodekrans greenstone belt are quartz-normative tholeiites whereas the basaltic komatiites from Barberton are normatively quartz-free in most cases. AFM and CMA plots (Figure 4) show that the Roodekrans basalts cluster in a field transitional into 1. the field of tholeiitic pillow basalts from the Archaean volcanic belts in the Kalgoorlie-Norseman region of the Western Australian Shield (Hallberg, 1972), and 2. various basaltic and peridotitic komatiites from the Barberton greenstone belt. The AFM plot shows a continuous evolutionary trend from peridotitic and basaltic komatiites (the latter rocks from the Nelshoogte Schist Belt in the Barberton area - Anhaeusser, in preparation), through the Roodekrans Mg-rich volcanics into the Western Australian Archaean tholeiites. The CMA plot, like the AFM plot, serves to illustrate the separation of the Mg-rich basalts from other classes of Archaean volcanic rocks. Detailed mapping and geochemical studies carried out recently in a number of southern African greenstone belts are confirming the widespread distribution of rocks of this composition (Grobler, 1972; Minnitt, 1975; M. Prinsloo and M.J. Viljoen, personal communication, 1976). They are commonly associated with komatiitic basalts and have received only cursory attention thus far.

The relationship between the Roodekrans type high-Mg basalts and the ultramafic rocks in the area appear to be one of crystallized partial melt to residue of melting. The bulk composition data on these rocks, shown in Figure 5, supports this interpretation but does not offer a complete fractionation trend between all the possible melt and cumulate phases that are commonly encountered in Archaean greenstone terranes. This aspect will be discussed more fully later.

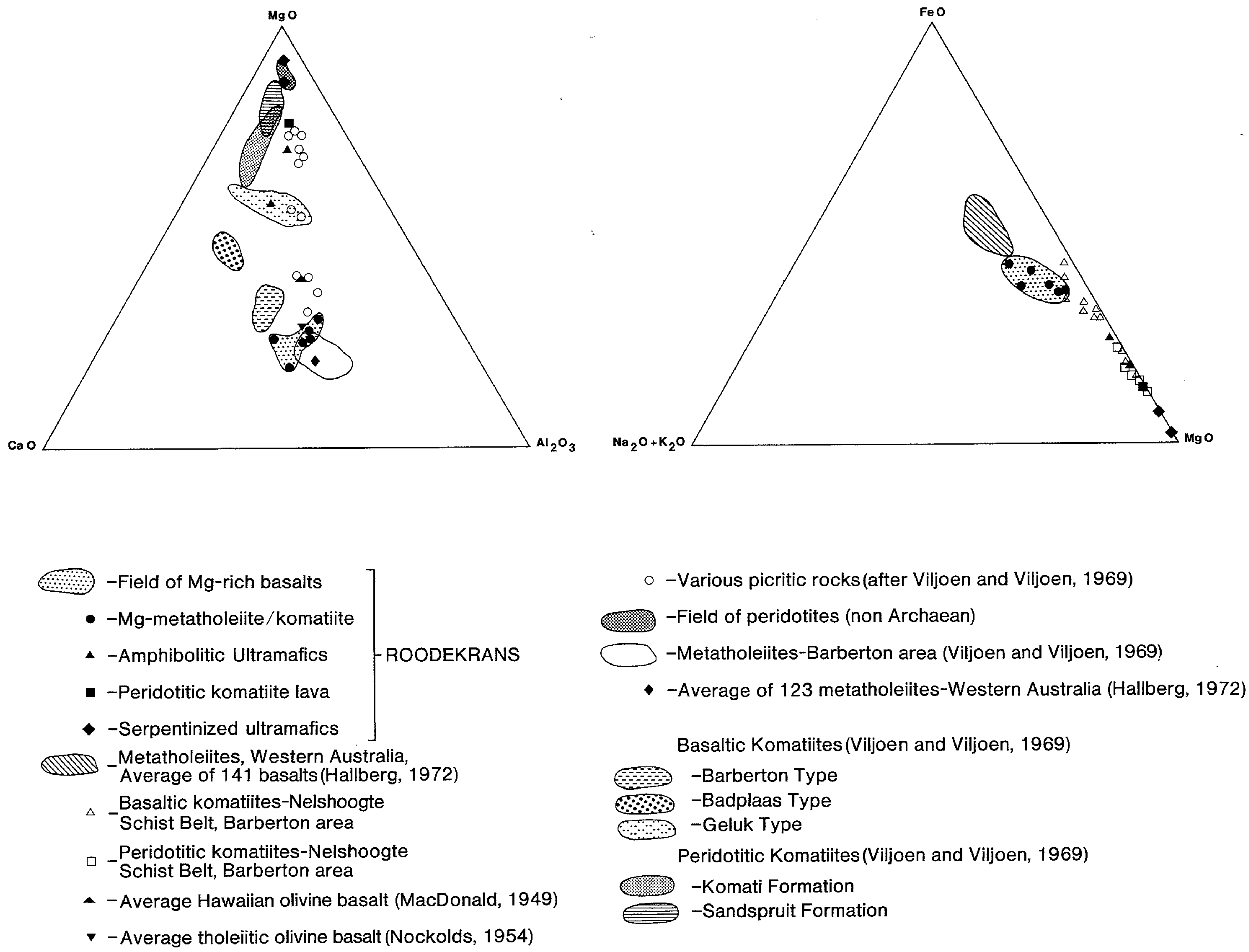

Figure 4 : CMA and AFM plots for mafic and ultramafic rocks from the Roodekrans greenstone remnant. The fields of various Archaean peridotites, komatiitic basalts and tholeiites from the Barberton Mountain Land, South Africa, and the Eastern Goldfields region of Western Australia are shown for comparison. Supplementary data from the Nelshoogte Schist Belt, Barberton is included in the AFM diagram and plots of various picritic rocks and olivine basalts are shown in the CMA diagram.

In Figure 5, some of the oxide abundances are plotted against MgO, resulting in linear trends for most elements. Also shown in the diagrams are the positions of average dunite, orthopyroxenite, and websterite analyses from various layered differentiated ultramafic complexes in the Barberton Mountain Land (Anhaeusser, 1969; 1976; and paper in preparation; Viljoen and Viljoen, 1969d). In addition, Hallberg's (1972) average Western Australian Archaean tholeiitic pillow basalt is plotted in the diagram. Extraction of melts, and cumulates of peridotitic, dunitic, and orthopyroxenitic composition, from a starting liquid containing approximately 25 per cent MgO (average peridotitic komatiite liquid) will drive the composition of the residue along a line extending towards the Mg-rich basalts. This suggests that olivine and orthopyroxene fractionation were important in controlling the development of melts with less than 25 per cent MgO, a feature discussed by McIver and Lenthall (1974).

Two important distinguishing components of Archaean mafic and ultramafic rocks, viz. calcium and aluminium, are plotted against each other in Figure 6. Also shown in this diagram are the fields of the various komatiitic and tholeiitic rocks as defined by Viljoen and Viljoen (1969b) for the Barberton successions. The Roodekrans Mg-rich basalts have Ca/Al ratios (± 0,8) broadly comparable with those of most classes of tholeiite but are slightly more enriched in both Al_2O_3 and CaO. One sample of pillow basalt (R021, Figure 3, A1) has affinities with Barberton type komatiites whereas

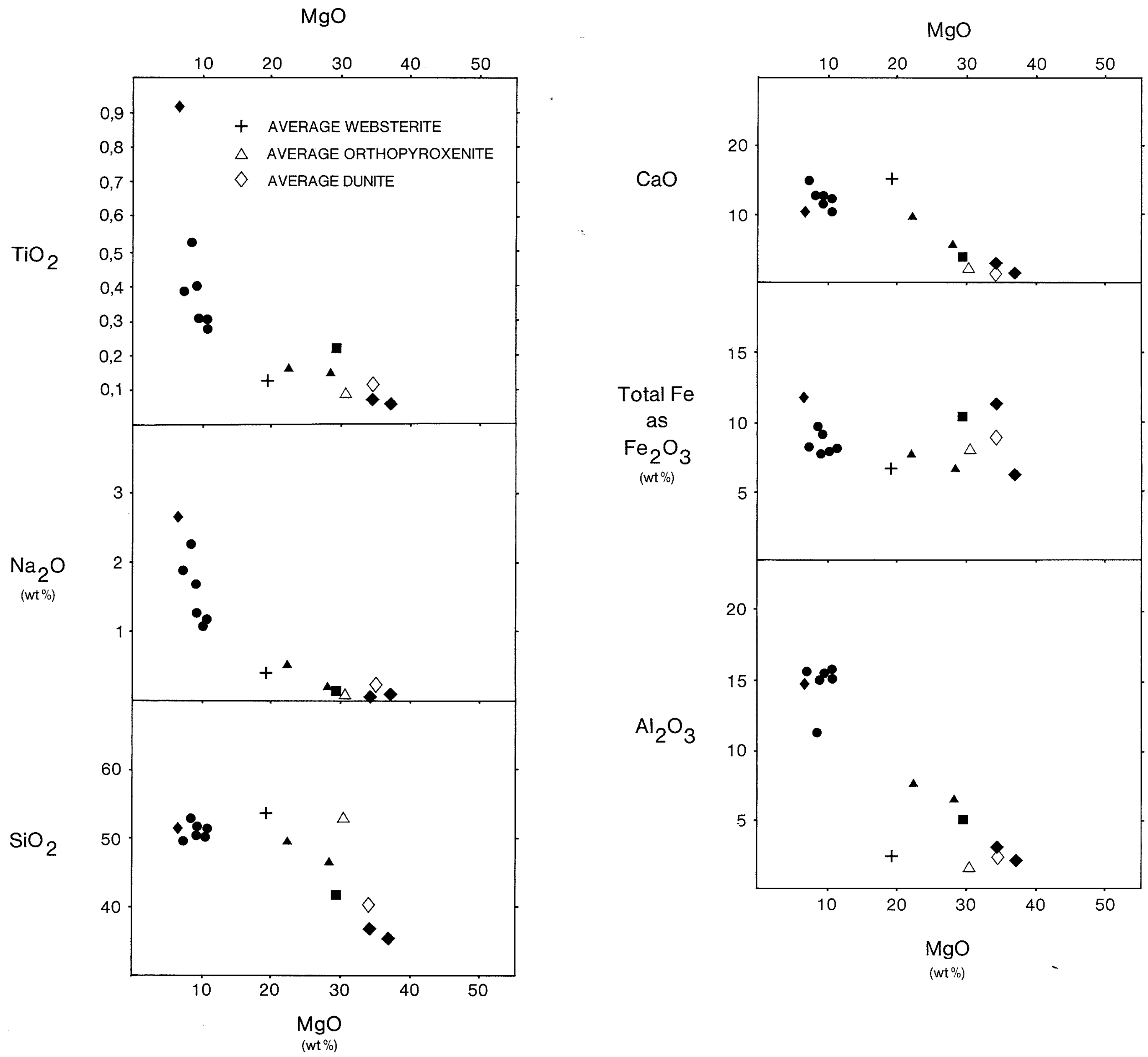

Figure 5 : Bulk compositional variation in the mafic and ultramafic rocks from the Roodekrans area and listed in Table 1, columns 1-11. Individual points may be identified by reference to their MgO contents. Symbols used in the diagram are the same as those shown in Figure 4. Additional points include average dunites, orthopyroxenites, and websterites from the Barberton layered differentiated complexes (Anhaeusser, 1969; 1976; Viljoen and Viljoen, 1969d).

sample R012 from the Roodekrans layered sequence (Figure 3, B2) plots near the field of the Geluk type basalts - a feature mentioned earlier. Both these samples have Ca/Al ratios greater than 1, which is one of the diagnostic chemical attributes of komatiites (Brooks and Hart, 1974; Viljoen and Viljoen, 1969b).

(d) Possible Genetic Relationships of Archaean Mafic and Ultramafic Igneous and Eruptive Rocks

It has been shown that the Roodekrans type Mg-rich basalts constitute part of what appears to be a continuous trend of magma evolutionary development involving, in addition, peridotitic komatiites, three varieties of basaltic komatiite (Barberton, Badplaas and Geluk types - Viljoen and Viljoen, 1969b), and Archaean tholeiites of the type reported from Canada, Western Australia, India, and southern Africa (Hallberg, 1972; Naqvi, 1971; Viljoen and Viljoen, 1969b; Wilson et al., 1965). Furthermore, if the cumulus-enriched phases of the Archaean layered, differentiated, ultramafic complexes are taken into account an almost complete evolutionary trend of magma development

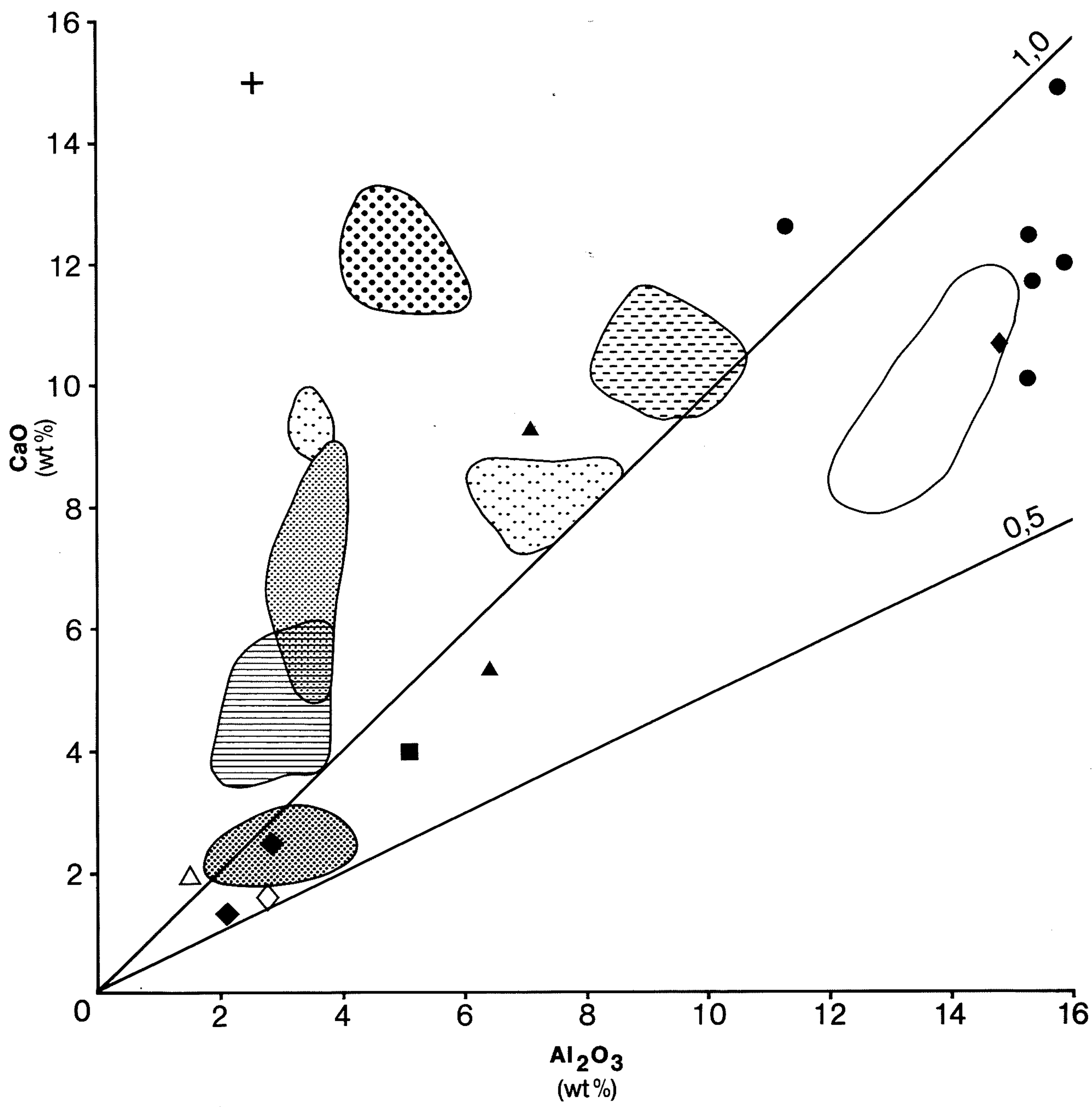

Figure 6 : Binary variation diagram showing plots of CaO vs. Al_2O_3 for the rocks of the Roodekrans area. Symbols and data fields are the same as those shown in Figures 4 and 5.

can be demonstrated. To do this the writer has included as yet unpublished chemical data, from the Nelshoogte Schist Belt and the Stolzburg differentiated body in the Barberton Mountain Land (Anhaeusser, in preparation), in binary variation diagrams shown in Figure 7.

The oxide abundances of SiO_2 and CaO are plotted against MgO for a full range of rock types which, from field observations, have been regarded as contemporaneous or consanguineous in origin. By contrast with the binary plots shown in Figure 5, it is evident that the supplementary chemical data does not define a simple linear trend of magma evolution between the cumulus olivine component on the one end of the scale and eruptive tholeiitic basalts at the other end. Rather, a more involved fractionation history than that proposed by McIver (1975) is apparent. Inset diagrams which accompany the data plots attempt to explain the magma evolution trends. In these diagrams it is assumed that the composition of the parental or starting liquid is located somewhere in the vicinity of the point A (peridotitic komatiite liquid). In Figure 7A, extraction of cumulus-enriched liquids, commencing with olivine fractionation (producing dunites), drives the composition of the residue along a line joining the dunites (theoretical value TD*) to point A and on to BK (basaltic

* Footnote : Theoretical dunite chosen on the basis of the olivines being particularly Fo enriched (Fo93-Fo100, Anhaeusser, 1972; Viljoen and Viljoen, 1969d). The Stolzburg dunites are serpentinized, effecting a lateral shift to lower MgO values).

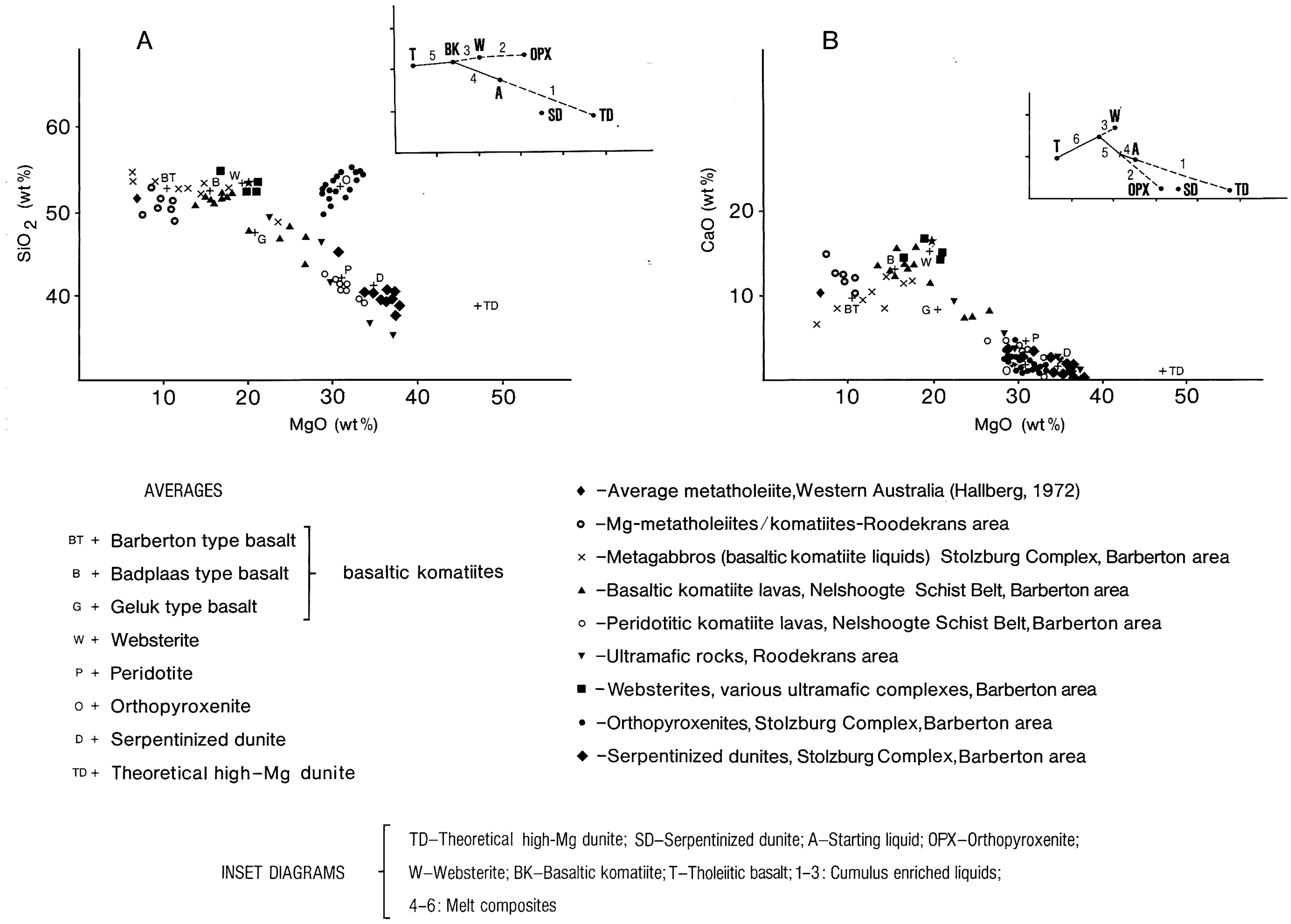

Figure 7 : Binary plots of SiO_2 and CaO vs. MgO for rocks of the Roodekrans area and supplemented by unpublished data (Anhaeusser, in preparation) from the Nelshoogte Schist Belt and Stolzburg layered differentiated complex in the Barberton greenstone belt. Inset diagrams show the evolutionary trends of development of cumulus enriched liquids and composite melts resulting from olivine, orthopyroxene and websterite fractionation.

komatiites). Further extraction of orthopyroxene (OPX) and clinopyroxene (W) cumulus liquid phases causes inflection of the trend through the field of various melt composites (basaltic komatiites, Mg-rich basalts) to the tholeiite basalt field (T).

Similarly in Figure 7B, olivine is first to fractionate from starting liquid A. Olivine extraction drives the residue through and beyond A where the line of evolution is deflected by the influence of orthopyroxene fractionation and projects along melt path 5 to some point in the basaltic komatiite field. Further fractionation, involving the extraction of cumulus-enriched websterite, drives the remaining residue along the melt composite path 6 towards the Archaean tholeiite field (T). These trends can be demonstrated for most elements but they are particularly apparent in the SiO_2 and CaO vs MgO variation diagrams.

IV. CONCLUSIONS AND DISCUSSION

The Roodekrans Greenstone Complex can be divided into two principal components - rocks belonging to a layered ultramafic sequence and rocks forming part of a succession comprised essentially of Mg-rich pillow basalts and subordinate peridotitic interlayers. Although no unequivocal solution is provided for the essentially altered rocks of the layered sequence it is the writer's opinion that the ultramafic components do not constitute part of a layered differentiated sequence like those reported from the Barberton Mountain Land (Anhaeusser, 1976; Viljoen and Viljoen, 1969d). Rather it is considered more likely that the layered rocks represent an eruptive succession of possible ultramafic flow units like those described from Munro Township, Ontario (Pyke et al., 1973) and the Komati Formation in the Barberton greenstone belt (Viljoen and Viljoen, 1969a). This conclusion is based mainly on comparisons of geochemical data which, in cases of this nature, appear to be possibly the only reliable methods by which such a problem might be resolved.

The metabasaltic pillow lavas in the Roodekrans area were found to be mainly high-Mg tholeiites (7-11% MgO) the latter being gradational into low-Mg varieties (> 9% MgO) of basaltic komatiite (Barberton type). From their geochemical characteristics the Roodekrans type Mg-rich basalts appear to be transitional between basaltic komatiites and oceanic tholeiites. They represent a distinctive class of Archaean volcanic rocks and have been recognized in a number of southern African greenstone belts frequently closely associated with mafic and ultramafic komatiite eruptives. Geochemical data from the Roodekrans area, coupled with data from the Barberton layered differentiated complexes and neighbouring volcanic sequences, suggests (Figure 7) that the mafic-ultramafic rocks characteristically encountered at the base of southern African greenstone belts are genetically linked and appear to form a continuum of intergradational magma types the chemical attributes of which are probably imposed by shallow depths of formation and high degrees of partial melting. Olivine, orthopyroxene, and clinopyroxene fractionation appears to have been important in controlling the development of the komatiite-type extrusives and associated tholeiitic basalts.

If, as has been argued (Cawthorn and Strong, 1974), komatiites do not constitute a distinctive isolated new class of basic and ultrabasic magma but a more extreme composition in a spectrum of rocks with chemical characteristics imposed by limiting P-T conditions then such conditions as existed in the Archaean must be the deciding factor in the generation of these and related rocks. Petrologists have been quick to point out that komatiitic type rocks are not unique to the Archaean but have been found as isolated occurrences in a number of younger settings. Gale (1973) has reported several occurrences of basaltic komatiite in a lower Palaeozoic volcanic sequence in Newfoundland. These and associated low-K tholeiites, he maintained, were indicative of an oceanic-crust regime. This tectonic environment is bradly coincident with that proposed for the Archaean basal mafic-ultramafic sequences and supports the view that physico-chemical factors were paramount in the development of the komatiites and related rocks. Komatiites and high-Mg basalts are, however, the rule, not the exception, in the basal units of the southern African Archaean. As pointed out by Anhaeusser et al. (1969) the distinctive and probably unique factor which can be associated with the greenstone belts is their geotectonic setting and their formation on a crust, the nature of which has never subsequently been simulated because of progressive thickening in later times. Thus, uniformitarianism cannot be upheld, but many of the volcanic and other features of greenstone belts have been reproduced separately in various environments throughout subsequent geological time.

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KEY TO PLATE 1

A. View across the southern portion of the Roodekrans Complex and showing the alternating quartzite shale units of the overlying Lower Division of the Witwatersrand Supergroup in the Witpoortjie Falls area.

B. Coarse-grained, homogeneous, porphyritic granodiorite intrusive into the northern contact zone of the Roodekrans greenstone remant.

C. Flattened and banded amygdaloidal and vesicular metabasalts located near the granite-greenstone contact (Figure 3, B2).

D. Relatively undeformed amygdaloidal and vesicular metabasalts near sample locality R018 (Figure 3, A2).

E. Pillow basalts showing relatively undeformed pipe amygdales. Locality near sample R018 (Figure 3, A2).

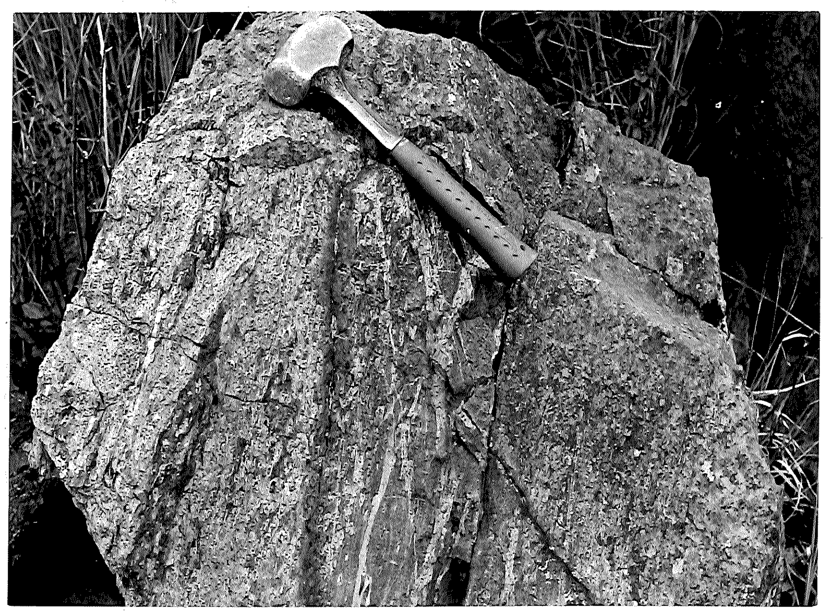
F. Hornfelsic metabasalt showing intense network of quartz veins, the latter probably developed as a result of post-metamorphic brittle deformation.

PLATE 1

A

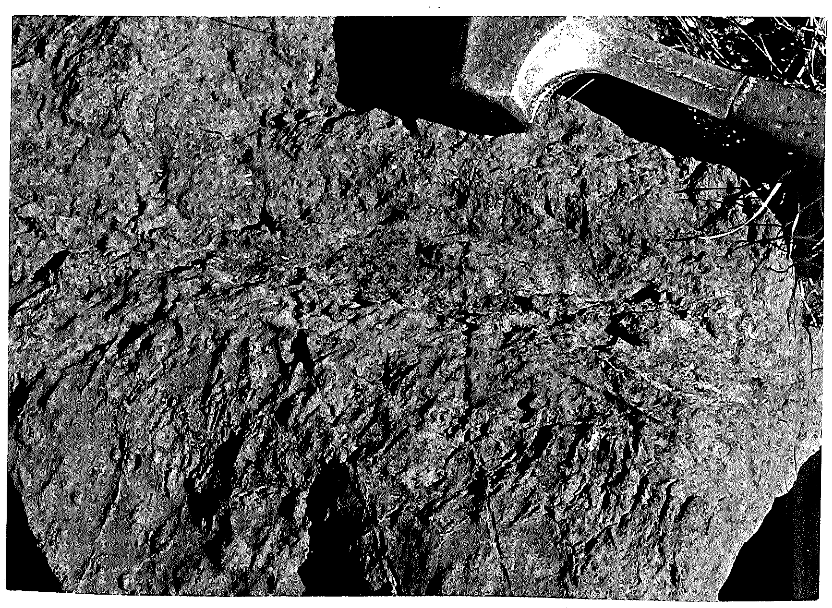
B

C



D

E



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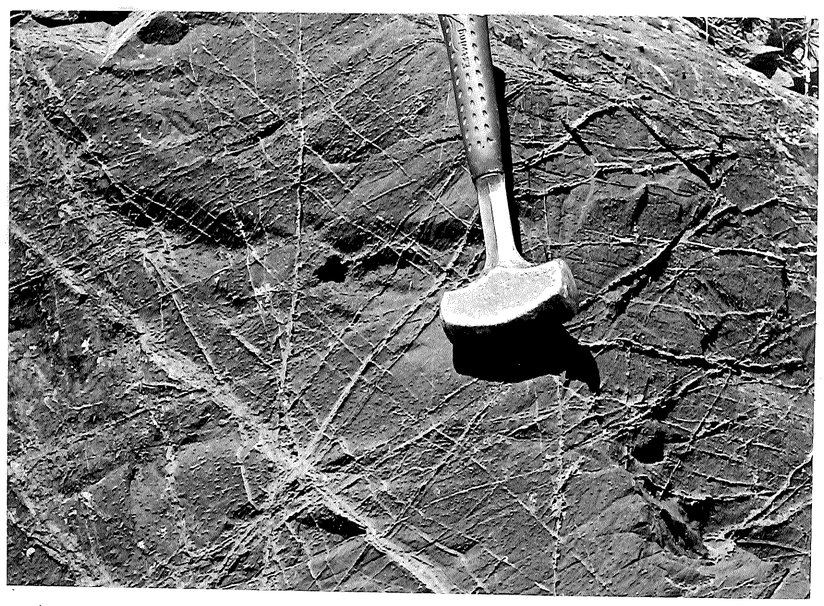
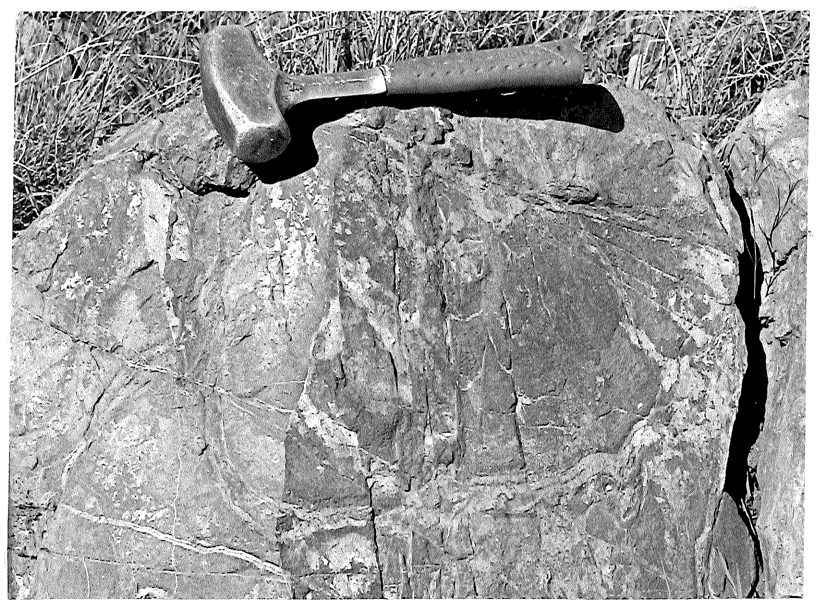


PLATE 2

A



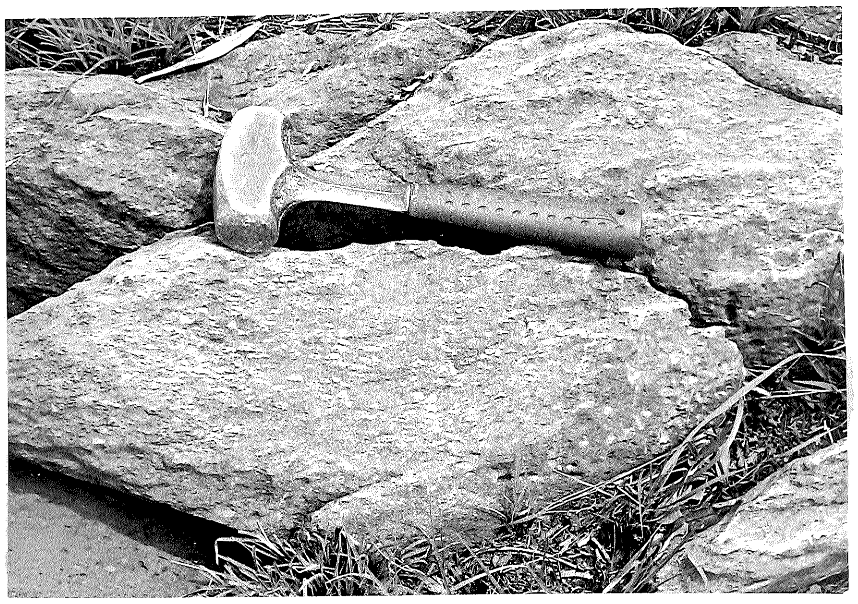
B

A. Rounded, relatively undeformed pillow basalt from sample locality RO 21 near the granite contact (Figure 3, A1)

B. Undeformed, irregular-shaped pillow basalt showing chilled selvedges and a tricuspate void filled with pillow breccia, quartz and carbonate. Locality near sample RO 21.

C

D



C. Vertically-dipping talc-chlorite schists from the southern part of the Roodekrans layered ultramafic sequence. A strongly developed oblique cleavage is developed in these rocks parallel to the hammer handle.

D. Altered ultramafic schists containing large irregular-shaped blebs of talc and carbonate. Locality near sample RO 12, Roodekrans layered ultramafic sequence (Figure 3, B2).