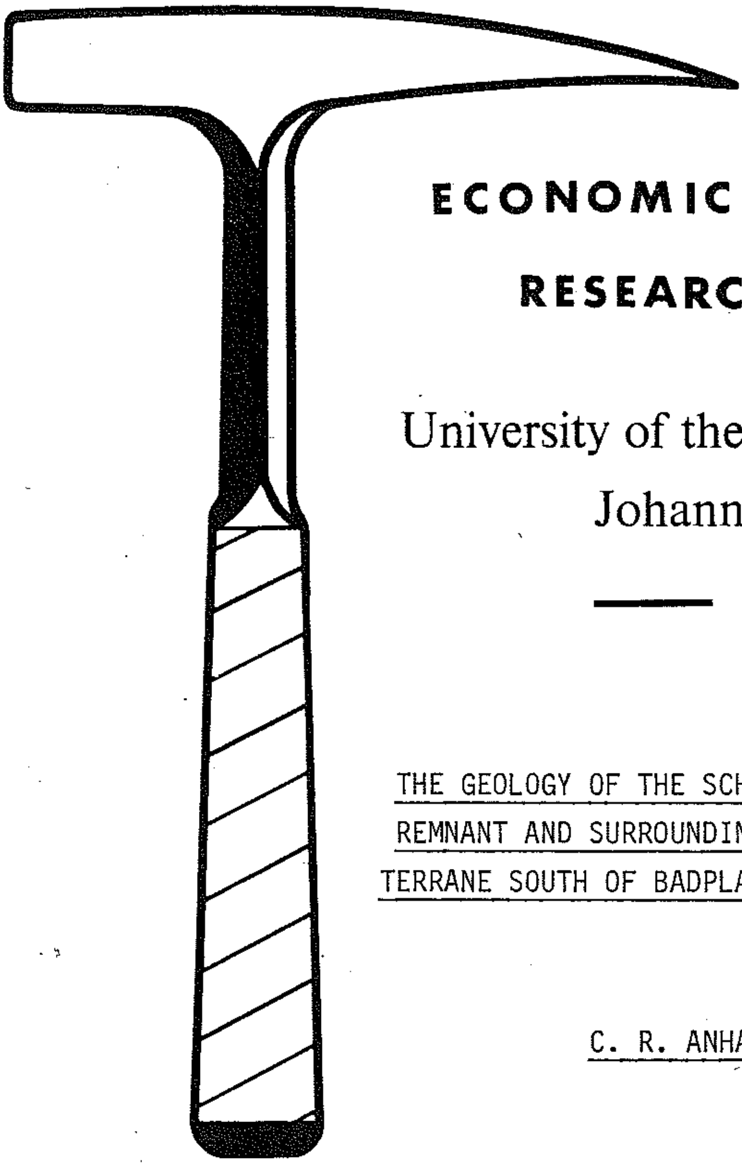

ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

THE GEOLOGY OF THE SCHAPENBURG GREENSTONE REMNANT AND SURROUNDING ARCHAEAN GRANITIC TERRANE SOUTH OF BADPLAAS, EASTERN TRANSVAAL

C. R. ANHAEUSSER

INFORMATION CIRCULAR No. 158

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

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by

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ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR NO. 158
December, 1981

South African Geodynamics Project Paper No. 68

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ABSTRACT

The Schapenburg greenstone remnant is one of a number of Archaean xenoliths preserved in the granitic terrane in the southern part of the Barberton Mountain Land. The greenstone belt, which is approximately 12 km long and 2,5 km wide where best developed, is made up largely of cyclically repetitive, regularly layered, volcano-sedimentary units. These units are generally comprised of a basal peridotitic komatiite flow overlain by a basaltic komatiite flow. A banded silicate-facies iron-formation usually terminates or caps each successive cycle. The mafic and ultramafic volcanics are generally serpentinized or altered to a wide variety of schists but locally the rocks show well-preserved spinifex textures and relic olivine crystals.

Unlike other greenstone xenoliths in the Barberton area the Schapenburg belt also contains a well-developed metagreywacke-metapelite sequence together with calc-silicate interlayers. The clastic metasediments are considered to be turbidites and contain mainly grunerite ± almandine ± cordierite ± andalusite ± staurolite ± epidote/zoisite as well as quartz and magnetite. The calc-silicate units, which are probably altered pelagic calcareous marls, are dominated by diopside ± garnet ± microline ± epidote/zoisite + quartz assemblages. The metamorphism resulted in incipient anatectic melting of the metagreywackes and indications are that the rocks were subjected to low-to-medium grades of metamorphism with temperatures ranging from 500-700^{o}C and pressures ranging from 2,5 - 3,5 kb (Abukuma facies series of Winkler, 1967).

The granitic rocks intruding the Schapenburg belt include components of the first and second magmatic cycles (as defined by Anhaeusser and Robb, 1981). Trondhjemite and tonalite gneisses and migmatites constitute the oldest intrusives (± 3,4 – 3,2 Ga), whereas granodiorites, adamellites, and K-rich marginal migmatites, associated with the Heerenveen and Mpuluzi batholiths south of the Barberton greenstone belt, represent the latest granitic events in the area (± 3,2 - 3,0 Ga).

The Schapenburg greenstone belt underwent an early deformational history linked with the emplacement of the Archaean granites and a later deformation involving NW-SE fracturing and dyke intrusion. This last event produced left lateral strike separation of the formations as well as segmentation of the belt.

From the field and geochemical evidence presented it is concluded that the Schapenburg greenstone remnant represents a xenolith comprised of the lowermost formations of the Onverwacht succession (Tjakastad Subgroup) of the Barberton greenstone belt.

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CONTENTS

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Published by the Economic Geology Research Unit
University of the Witwatersrand
1 Jan Smuts Avenue
Johannesburg 2001

ISBN 0 85494 718 3

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I. INTRODUCTION

Numerous greenstone inclusions or xenoliths occur in the Archaean trondhjemitic/tonalitic gneiss terrane south of the Barberton greenstone belt (Anhaeusser, 1980; Anhaeusser and Robb, 1980). As part of the regional and detailed mapping project associated with South Africa's contribution to the International Geodynamics Programme certain of the better developed greenstone relics were singled out for closer examination. Due to the fact that many of the greenstone remnants were not previously known it was considered necessary to investigate aspects relating to their stratigraphy, structure, and metamorphic character, as well as their mineralization potential.

This study documents field observations made in and adjacent to the Schapenburg greenstone remnant located approximately 30 km south of Badplaas, near the Jessievale Forest Station (Fig. 1). A detailed geological map of the granite-greenstone terrane, mainly straddling the farms Klipplaatdrift 179 IT, Schapenburg 178 IT and Welgevonden 175 IT, was compiled using aerial photographs enlarged to a scale of 1:10 000. The results of the field investigation are portrayed in the accompanying reduced geological map of the area (Fig. 2).

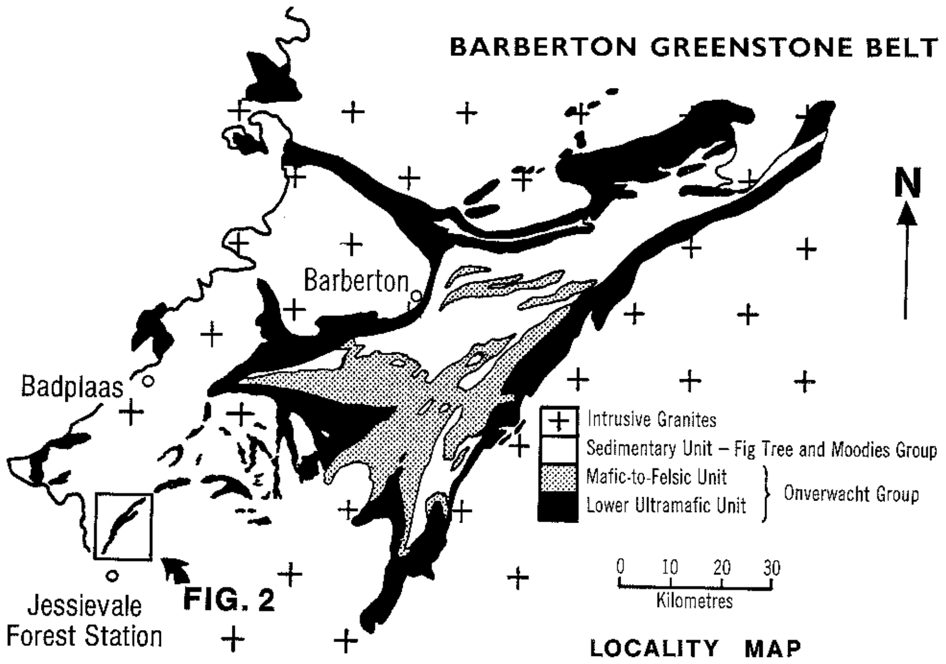

Figure 1 : *General geological map of the Barberton Mountain Land showing the distribution of some of the larger greenstone xenoliths south of Badplaas. A detailed map of the Schapenburg greenstone remnant, located north of the Jessievale Forest Station, is provided in Fig. 2, which is a fold out map at the back of the Information Circular.*

II. REGIONAL GEOLOGICAL SETTING

South of the Barberton greenstone belt lies an extensive tract of leucocratic biotite trondhjemite gneisses which generally form discrete diapiric plutons, the latter partially or, in some cases, almost entirely rimmed by greenstone selvedges. Associated with the trondhjemitic gneisses are complex migmatitic rocks (Anhaeusser, 1980; Robb, 1981, 1982), many of which were formed through the introduction of felsic magma into a once extensive ensimatic crust. Also recognized in the gneissic terrane are a number of newly defined trondhjemitic bodies, or "cells", the latter identified principally in terms of their distinctive geochemical characteristics (Robb and Anhaeusser, 1982). The cells are not easily identifiable field units as they are not necessarily elliptical in shape like the plutons nor are they outlined by greenstone selvedges.

Investigations by Viljoen and Viljoen (1969a, b) and Anhaeusser (1980) have indicated that the scattered greenstone fragments encountered in the gneisses are comprised entirely of assemblages characteristic of the lower formations of the Onverwacht Group of the Swaziland succession (namely, the Tjakastad Subgroup). Detailed mapping has shown that not only are the lithologies identical but, furthermore, they can be traced from the gneissic terrane directly into the Barberton greenstone belt in several areas.

Sm-Nd geochronological studies undertaken by Hamilton *et al.* (1979) suggest that the Barberton volcanic sequences are 3510 ± 60 Ma old and all available evidence indicates that these rocks were intruded by trondhjemites ranging in age from ≅ 3500 - 2750 Ma (Oosthuyzen, 1970; Barton, 1981; Barton *et al.*, 1982). These trondhjemites (and associated tonalites and migmatites) constitute part of the *first magmatic cycle* as defined by Anhaeusser and Robb (1981) and represent the commencement of granitic activity in the Barberton Mountain Land. Barton (1982) preferred, however, to subdivide the Rb-Sr whole rock isochron data from the leucocratic orthogneisses of the Eastern Transvaal and Swaziland into several age groups, defining his Group 1 as ∿ 3560 to ∿ 3430 Ma; Group 2 ∿ 3360 to ∿ 3070 Ma and Group 3 ∿ 2900 to ∿ 2730 Ma. Despite differences in approach there appears to be general agreement that an early period of tectonic activity involved partial melting of metabasalts (amphibolites) to form tonalitic and trondhjemitic magmas that in turn magmatically and diapirically intruded other amphibolitic rocks. Isotopic data suggests that the trondhjemitic rocks in the area were emplaced episodically over a time span of approximately 600 - 800 Ma. As Barton (1981, 1982) points out, however, the younger ages may reflect ages of emplacement (reset at the time of diapiric intrusion) that may be quite different from crystallization ages.

Caught up in the ancient trondhjemitic gneisses, and extending in a NE-SW direction, is the Schapenburg greenstone remnant which is described in detail later in this paper. This remnant forms part of a 'train' of sizable greenstone fragments, each several kilometres in extent, that link up with the Sandspruit and Theespruit formations 30 km ESE of Badplaas (Fig. 1). One of these, the Weergevonden remnant, has been described by Anhaeusser (1980), who reported numerous rock types including mafic and ultramafic assemblages, banded iron-formations and cherts, as well as felsic volcanic and pyroclastic rocks. Due to the intrusion of two diapiric trondhjemite gneiss plutons and the Boesmanskop syenite pluton (Anhaeusser *et al.*, 1982) the rocks of the Weergevonden remnant have been extensively deformed to a wide variety of mafic, ultramafic and felsic schists.

South of the Schapenburg-Weergevonden greenstone remnants is the Mpuluzi batholith, with the Heerenveen batholith occupying the area immediately north-west of the Schapenburg fragment (Anhaeusser and Robb, 1982). These,essentially massive, potassic bodies form components of the *second magmatic cycle* of Anhaeusser and Robb (1981) and are linked with a major crust-forming episode that commenced approximately 3200 Ma ago in the areas both north and south of Barberton and which terminated approximately 3000 Ma ago. The potassic batholiths are multi-component bodies consisting principally of coarse-grained, homogeneous, porphyritic granites, adamellites and granodiorites. They are intruded by isotopically coeval phases of adamellite and granodiorite and the batholiths, which form topographically elevated areas relative to the flanking trondhjemitic gneisses, are rimmed by K-rich migmatite and gneiss aureoles reflecting zones of interaction between the batholiths and the pre-existing crust (comprised of greenstone material and Na-rich gneisses and migmatites).

Apart from the presence of a number of syenite bodies that intrude the trondhjemitic gneiss terrane south of the Barberton greenstone belt, and which form part of a family of undersaturated rock types linked with the Boesmanskop syeno-granite complex (Anhaeusser *et al.*, 1982), magmatic activity in the southern part of the Barberton Mountain Land appears to have culminated with the emplacement of numerous mafic dykes and some sills. These intrusives, which are mainly diabases, have a preferred NW-SE strike direction over most of the region. Less common are NE-SW and north-south orientated dykes, the latter comprising mainly Karoo dolerites. Although no absolute ages are yet available for the various dyke varieties their relationship with rocks of the Transvaal Drakensberg escarpment west of the Barberton Mountain Land (Visser *et al.*, 1956) suggests they are mainly early or middle Proterozoic in age (*circa* 1800 - 2400 Ma). The Karoo dykes and sills were probably emplaced approximately 160-300 Ma ago.

The preferred north-west orientation of the mafic dykescoincides with the linear distribution of the syenite occurrences associated with the Boesmanskop syeno-granite complex as well as the major fracture or shear zones and present day hot springs that occur south-east of Badplaas. These features indicate a long and complex history of crustal disturbance dating back more than 3000 Ma ago (Anhaeusser, 1980).

III. GEOLOGY OF THE SCHAPENBURG GREENSTONE REMNANT AND SURROUNDING GRANITIC TERRANE

A. General

Wedged between the Heerenveen and Mpuluzi batholiths in the upper reaches of the Theespruit drainage system is the Schapenburg greenstone remnant which occurs as a narrow belt over 12 km long and varying in width between 2,3 - 0,3 km. The belt is widest in the south on the farm Klipplaatdrift 179 IT (Fig. 2) and is split into two north-east extending limbs by an intrusive tongue of tonalite gneiss on the south-eastern portion of the farm Schapenburg 178 IT. The eastern limb wedges rapidly from 1200 m to 300 m in width over a distance of 2 km before being engulfed by granitic rocks. The western limb, by contrast, extends in a north-easterly direction down the Theespruit valley and maintains a more constant width across much of Schapenburg 178 IT and the adjoining farm Welgevonden 175 IT. It does, nevertheless, taper gradually, over a distance of 7,8 km, from a maximum width of 1050 m in the south, to approximately 200 m in the north-east where it disappears in an alluvium-covered valley formed near the confluence of the Theespruit River and one of its tributaries (Fig. 2, C8). Beyond this valley the greenstone belt reappears and continues around the northern margin of the Mpuluzi batholith (Plate 1A) before linking with the Weergevonden greenstone remnant south of the Boesmanskop syenite pluton (Anhaeusser, 1980).

The southern extension of the Schapenburg belt is obscured in the forests on the Jessievale Forest Reserve and on the farm Vlakfontein 69 IT. Also developed in this area is a thin veneer of Karoo sediments that covers the Archaean granite-greenstone terrane and which forms a flat-lying plateau south-west of Jessievale.

On the farm Klipplaatdrift 179 IT the greenstone successions occupy relatively high-lying ground, ranging between 1500-1700 m above sea level, and made up of differentially weathered mafic and ultramafic schists, cherty units and metasediments (Plate 1B). Along the western flank of the Schapenburg schist belt the greenstone successions have been more deeply dissected by drainage channels associated with the Theespruit River and there is a rapid change in elevation from the granitic plateau associated with the Heerenveen batholith on the farm Vlakfontein 69 IT (elevation ± 1700 m) to the valley floor on Schapenburg 178 IT (elevation 1280 - 1340 m) (see Fig. 2 and Plate 1C).

The Heerenveen and Mpuluzi batholiths, separated by the narrow Schapenburg greenstone remnant, are discrete bodies, each possessing distinctive physical and chemical characteristics (Anhaeusser and Robb, 1982). As mentioned previously, both are multi-component intrusive bodies consisting of coarse-to-very-coarse porphyritic phases, the latter often cut by linear, commonly dyke-like bodies of homogeneous, medium-grained, pinkish-grey, adamellite. Elsewhere, this phase has been referred to either as the Homogeneous Hood or Lochiel granite (Viljoen and Viljoen, 1969b; Hunter, 1974) and in places it forms what appears to be a carapace that is only preserved in high-lying terrain.

The Mpuluzi batholith consists predominantly of a medium-to-coarse-grained porphyritic, pinkish adamellite together with some granodiorites and even tonalitic gneisses in the marginal migmatite zones. The Heerenveen batholith has a central core zone consisting of very coarse megacryst-rich, high alkali trondhjemites, and an outer zone of adamellites and granodiorites. Both the batholiths have features in common with the multi-component Nelspruit batholith situated north of the Barberton greenstone belt and all appear to have been emplaced approximately 3200-3000 Ma ago (Anhaeusser and Robb, 1982; Barton *et al.*, 1982; Robb *et al.*, 1982).

The Schapenburg greenstone remnant is flanked by zones of trondhjemitic and granodioritic migmatites which generally pass gradationally into the massive, homogeneous, porphyritic batholiths. In some areas, however, the pinkish or pinkish-grey adamellites can be found immediately juxtaposed to the schist belt, a situation that appears in some cases to be a result of faulting.

The greenstone successions and the flanking granitic rocks are cut by numerous mafic dykes and fractures, the majority of which are aligned in a NW-SE direction. These dykes and fractures cause segmentation of the schist belt and, in some cases, are responsible for the left lateral strike separation of the formations in the segments (e.g. Fig. 2, B2, B6, B7).

B. Stratigraphy of the Schapenburg Greenstone Remnant

Under this heading are described the rock types comprising the greenstone remnant shown in Fig. 2, and evidence will be provided suggesting that most of the lithologies are readily correlatable with successions found in neighbouring greenstone xenoliths as well as in the Barberton greenstone belt.

1. Mafic and Ultramafic Assemblages

As is generally the case with all the greenstone xenoliths found in the areas south of the Barberton greenstone belt the principal rock types encountered in the Schapenburg suite are mafic and ultramafic massive and schistose rocks. The mafic rocks comprise a variety of amphibolites, including black hornblendites which are mostly developed in the areas immediately flanking the surrounding granitic rocks. Elsewhere throughout the area the rocks comprise dark greenish amphibolites containing mainly actinolite, but also including tremolite, chlorite, or talc-chlorite assemblages. In most cases the mafic rocks have been extensively deformed and occur as schists which are regularly interlayered with banded iron-formations and a variety of ultramafic rock types (Plate 1 B-D). In some areas, however, the mafic rocks are relatively undeformed and chemical analyses indicate that they are predominantly high-magnesian komatiitic basalts (Table 1, columns 4-6).

The ultramafic rocks have, with few exceptions, also been extensively altered to serpentinite or a variety of ultramafic schists including tremolite, talc-chlorite, talc-carbonate and talc schists. The serpentinites commonly form prominent north-east striking ridges (Plate 1D) and the ultramafic schists tend to occur as low, irregular, "dog- or shark-tooth" outcrops (Plate 1B).

As with the metabasalts some of the ultramafic rocks have also withstood the thermal and tectonic influences and rare examples exist where the original textural and mineralogical characteristics of the rocks have been preserved (Plate 1E). The best area of preservation of spinifex-textured peridotitic as well as basaltic komatiites occurs on the farm Klipplaatdrift 179 IT (Fig. 2, B2) where, despite the close proximity of the granitic rocks in the area, the textures are remarkably intact. The area shown on the map as a wide zone of ultramafic rocks (near sample localities JV 38 and JV 40) consists of numerous flow units, mostly of peridotite, but also including some thin interflow basalts. Although the textures are generally well-preserved the outcrops are jagged and discontinuous and difficulty was experienced in establishing facing directions.

The internal subunits are identical to those described by Pyke *et al.*, (1973) for the ultramafic flows in Munro Township, Ontario, as well as the komatiite flows described from the Komati Formation in the Barberton greenstone belt (Viljoen and Viljoen, 1969; Smith, 1980; Viljoen *et al.*, 1982). The flows have basal units consisting of medium-to-fine-grained peridotite overlain by long bladed olivine crystals (plate spinifex) in a coarse-textured spinifex zone. The size of the bladed crystals decreases progressively upwards into a random spinifex zone and the flow units have chilled and fractured flow tops (Anhaeusser, 1982 - in prep.).

A sample of random spinifex-textured peridotite (Fig. 2, JV 40) showed that the rock contains well-preserved skeletal crystals of olivine and clinopyroxene, the latter minerals altered, in part, to antigorite and tremolite together with accessory amounts of magnetite and chlorite. An analysis of sample JV 40 is listed in Table 1, column 2, and shows the distinctive geochemical characteristics of peridotitic komatiites, including high magnesium, and a high calcium-aluminium ratio. Of particular significance is the low loss-on-ignition value obtained from the sample (the average of two additional check analyses is listed in Table 1, column 3), indicating the low degree of alteration. Studies undertaken on ultramafic flows from the classic type section of the Komati Formation in the Barberton greenstone belt generally indicate a higher degree of serpentinization, with H_2O contents ranging between 5 and 10 per cent (Viljoen and Viljoen, 1969c; Smith, 1980). The analysis of the Schapenburg peridotite is particularly important since random spinifex material is generally regarded as the liquid portion of a flow from which all, or nearly all, of the suspended olivine phenocrysts have settled. The random spinifex zones, it is suggested by Smith (1980), provide the best compositional estimate of the initial liquid (phenocryst free magma). If these considerations are correct the Schapenburg ultramafic flows were probably derived from primary magma possessing MgO contents in the range 25-27 per cent.

A second locality where relic olivine was observed in the ultramafic flow units occurs approximately 1 km north of the above-mentioned spinifex komatiite zone. In this region (area surrounding sample JV 23 - Fig. 2, B3 and Plate 1D) there are numerous cyclically developed units comprising ultramafic rocks, metabasalts and banded iron-formations. The ultramafics are mostly altered to serpentinite and some of the units consist of medium-to-coarse porphyritic harzburgite or lherzolite, which probably represent cumulate concentrations of olivine and pyroxene in some of the flows. In most cases the original minerals are replaced by antigorite or tremolite with magnetite a prominent accessory. Sample JV 23 contains remnant olivine which, together with antigorite and tremolite (altered from diopside), have a boudinaged texture resulting from the regional flattening imposed on the formations by the intrusive granitic rocks. An analysis of JV 23 is listed in Table 1, column 1, and demonstrates the increased MgO and H_2O contents of the serpentinized harzburgite and a corresponding decrease in all other major elements, relative to the fresh spinifex ultramafics described from sample locality JV 40.

TABLE 1

CHEMICAL ANALYSES OF SOME ROCK TYPES FOUND IN THE SCHAPENBURG GREENSTONE REMNANT AND IN THE SURROUNDING GRANITIC TERRANE

Column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sample	JV23†	JV40A∆	JV40B†	JV38∆	JV 4∆	JV12A∆	JV12∆	JV14∆	JV24∆	JV30†	ET12∆	JV 2†	JV18†	JV21†	JV22†	JV34†	JV 7∆	ET 7†	JV27†	JV35†
SiO_2	42,59	46,00	46,64	49,30	53,30	54,40	50,80	59,00	65,60	54,53	73,80	69,92	66,03	67,65	65,79	76,38	69,60	74,19	72,82	74,98
TiO_2	0,22	0,39	0,39	0,51	0,47	0,85	0,29	0,66	0,47	0,43	0,26	0,43	0,46	0,46	0,44	0,44	0,28	0,20	0,27	0,19
Al_2O_3	2,77	3,90	4,09	5,50	5,22	9,00	8,20	14,50	15,70	9,53	13,70	16,15	16,03	16,04	15,79	16,14	10,90	13,22	13,51	14,05
Fe_2O_3*	11,49	11,90	12,17	15,30	12,00	12,90	32,20	12,70	3,96	7,91	2,18	2,75	3,94	3,85	4,36	3,56	3,18	1,35	1,76	1,24
MnO	0,13	0,17	0,19	0,20	0,21	0,22	0,82	0,20	0,08	0,50	0,03	nd	0,07	0,08	0,25	0,09	0,48	0,03	0,07	nd
MgO	32,12	26,70	25,38	17,30	13,60	9,97	4,60	5,60	1,60	7,20	0,80	1,15	2,21	2,30	1,96	2,04	4,30	0,11	0,63	0,43
CaO	2,65	7,30	7,16	10,10	12,50	9,63	1,97	1,54	3,71	16,46	2,89	3,31	4,28	3,78	3,86	3,88	4,32	0,93	0,98	0,95
Na_2O	0,31	0,50	0,79	1,30	1,30	1,80	1,40	1,60	4,80	2,20	4,20	3,59	4,14	3,76	3,68	3,74	2,70	4,19	3,34	3,01
K_2O	0,03	nd	nd	nd	0,18	0,29	0,16	2,56	2,28	0,92	1,07	1,57	2,32	2,31	2,44	2,25	2,78	4,50	4,93	5,26
P_2O_5	nd	0,04	0,07	0,06	0,10	0,09	0,10	0,11	0,25	nd	0,07	0,12	0,17	0,17	0,18	0,17	0,07	0,07	0,03	0,08
L.O.I.	8,70	2,90	4,01	0,70	0,60	0,38	0,67	1,07	0,87	1,11	0,50	1,76	1,21	1,17	1,99	1,09	0,66	0,59	1,14	0,81
TOTAL	100,99	99,80		100,27	99,48	99,53	101,21	99,54	99,32	100,79	99,50	100,75	100,86	101,57	100,74	100,79	99,27	99,18	99,48	101,00
Rb	-	-	-	-	-	-	-	-	-	86	28	-	78	73	67	149	-	319	218	222
Sr	-	-	-	-	-	-	-	-	-	327	380	-	943	856	962	757	-	114	217	105
Ba	-	-	-	-	-	-	-	-	-	224	110	388	1089	889	1076	865	-	425	940	515

Analysts : † Department of Geology, University of the Witwatersrand ∆ Bergström and Bakker, Johannesburg

* Total Fe as Fe_2O_3

Column
1. Serpentinized harzburgite (locality - Fig. 2, B3).
2. Spinifex textured peridotitic komatiite (locality - Fig. 2, B2).
3. Average of two analyses of spinifex textured peridotitic komatiite - same sample as JV40A.
4. Komatiitic metabasalt (locality - Fig. 2, B2).
5. Komatiitic metabasalt (locality - Fig. 2, B2).
6. Komatiitic metabasalt (locality - Fig. 2, B1)
7. Garnetiferous metagreywacke (locality - Fig. 2, B1).
8. Metagreywacke (locality - Fig. 2, B1).
9. Calc-silicate rock (locality - Fig. 2, B2).
10. Calc-silicate rock (locality - Fig. 2, A4).
11. Trondhjemitic gneiss (locality - Fig. 2, B7)
12. Tonalite intrusive into Schapenburg greenstone remnant (locality - Fig. 2, B1).
13. Tonalite with mafic inclusions (locality - Fig. 2, B3).
14. Tonalitic gneiss (locality - Fig. 2, C4).
15. Tonalitic gneiss (locality - Fig. 2, B4).
16. Pinkish-grey tonalite/granodiorite gneiss (locality - Fig. 2, B5).
17. Pinkish-grey granodioritic gneiss (locality - Fig. 2, B2).
18. Pinkish-grey granodioritic gneiss (locality - Fig. 2, C7).
19. Pinkish-grey adamellite (locality - Fig. 2, A3).
20. Homogeneous pinkish-grey adamellite of the Mpuluzi batholith (locality - main road, near Jessievale plantation on farm Klipplaatdrift 179 IT).

2. *Volcanic and Sedimentary Cyclicity*

One of the most outstanding aspects of the geology of the Schapenburg greenstone belt is that it demonstrates clearly a cyclical pattern of volcanism and sedimentation, the regularity and nature of which have never before been witnessed or documented in rocks making up the basal mafic-ultramafic successions of Archaean greenstone belts, either in southern Africa or elsewhere. Cyclical volcanism is a common, if not characteristic, feature of Archaean greenstone belt development (Anhaeusser, 1971; Goodwin, 1977). However, most of the well-developed volcanic cyclicity occurs in the upper stratigraphic units of the southern African greenstone belts, such as in the Geluk Subgroup of the Barberton volcanic pile (Fig. 3B, and Viljoen and Viljoen, 1969d), and in the essentially calc-alkaline sequences of Archaean volcanic terranes elsewhere in the world (Ayres, 1977; Baragar and Goodwin, 1969; Glikson, 1976; Goodwin, 1977).

In the Schapenburg greenstone belt well-developed volcanic cyclicity occurs across the entire stratigraphic section exposed, but is particularly well-defined on the farm Klipplaatdrift 179 IT (Fig. 2, B1-3; Plate 1B and D). Upwards of 20 cycles are exposed on the eastern limb of the belt whereas on the farm Schapenburg 178 IT at least 10 cycles are developed on the western limb (Fig. 2, A4, B4). Each volcanic cycle consists of at least two components, namely a basal peridotitic komatiite unit and an overlying basaltic komatiite unit. The cycles are frequently capped or terminated by banded iron-formations (Fig. 3A) but these may be missing in some cases, either because they were never deposited or because they are not exposed. The banded iron-formations terminating each cycle are seldom thicker than approximately 5 m and may be less than 1 m wide in some cases. Outcrops are generally ankle-high or are flush with the ground-level but in some cases low, discontinuous, ridges are present (Plate 1F and Plate 2A) that can be traced intermittently for distances exceeding 4 km. The iron-formations form useful marker beds and in most cases their thicknesses on the map (Fig. 2) has had to be exaggerated in order to portray their presence.

The iron-formations are generally well-banded (Plate 2A) and appear to be ferruginous and even gossanous in places on the weathered outcrops. The rocks consist of layers of recrystallized chert alternating with brown-weathering amphiboles. The chert layers, which are seldom wider than 5 cm (average 2 cm), form discontinuous lenses as well as boudinaged segments along strike. The amphibole bands have similar thicknesses and are proportionately more abundant than the cherty bands. This approximately 2:1 relationship probably accounts for the low resistance these rocks have to weathering.

In thin section the amphibole-rich bands consist predominantly of polysynthetically twinned, fibrous or bladed crystals of grunerite. In some cases hornblende is the dominant amphibole and in others the two amphiboles appear together in the same rock. Minor amounts of actinolite and chlorite are present and magnetite and quartz are developed in variable amounts. In some sections examined the magnetite is preferentially developed in certain amphibole bands and is virtually absent in others. The cherty zones consist almost exclusively of recrystallized quartz.

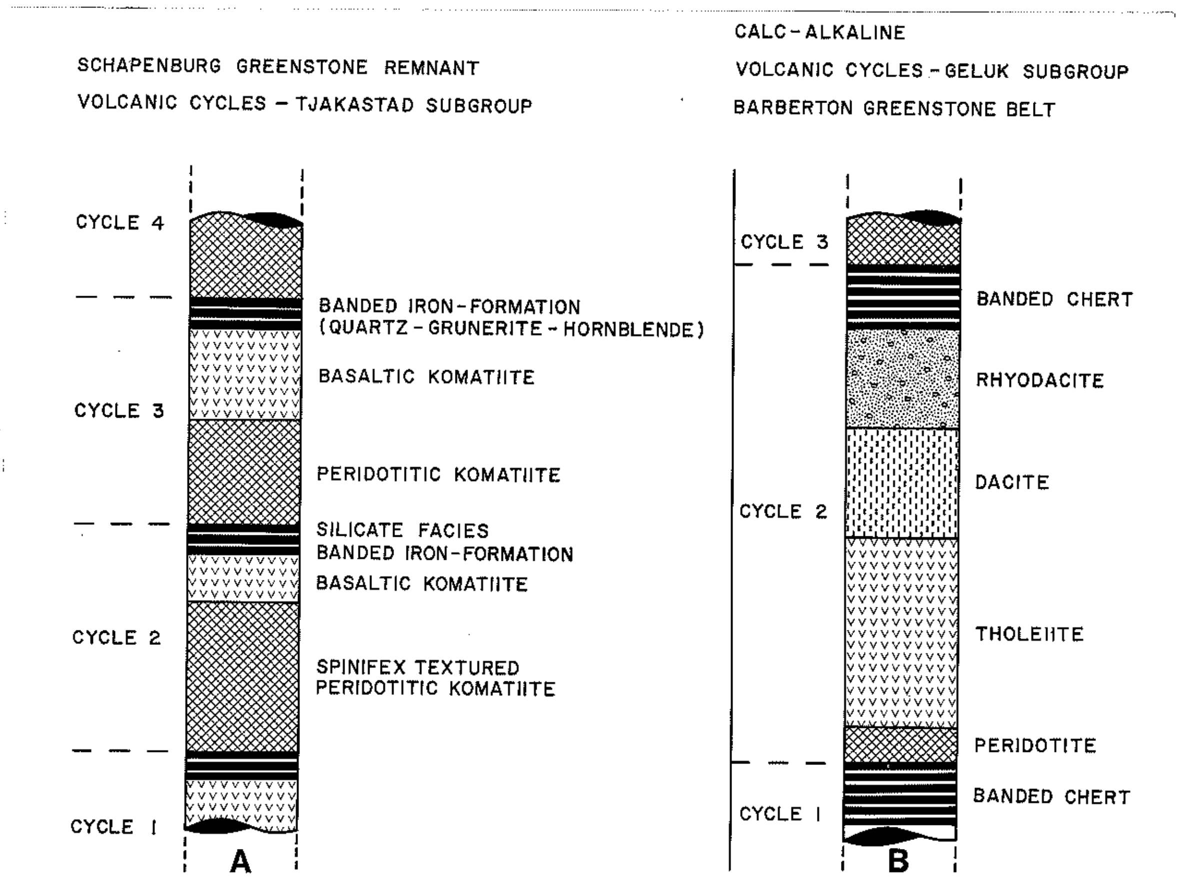

Figure 3 : *A. Schematic column illustrating the nature of the rock types and their relative order of development in volcano-sedimentary cycles in the Schapenburg greenstone remnant. B. Schematic column showing the components of a typical volcanogenic cycle forming part of the calc-alkaline sequence of the Geluk Subgroup (Onverwacht Group) in the Barberton greenstone belt. Volcanic cycles from this region range between approximately 500-1000 m in thickness (Viljoen and Viljoen, 1969d), whereas the Schapenburg cycles are seldom thicker than 100 m.*

Mineralogically, the banded iron-formations are essentially of the silicate facies type but there is no evidence, due largely to the masking effect imposed by the prevailing greenschist facies metamorphism, of the primary nature of the iron silicate minerals. Greenalite is probably the strongest contender as it is one of the few silicate minerals present in iron-formations that is considered to be of certain primary origin (James, 1954). Minnesotaite, stilpnomelane and chlorite may also have been present together with magnetite and carbonate. The optimum conditions for precipitation of silicates was considered by James (1954) to be in the range from mildly oxidizing to mildly reducing. Iron silicate he noted, either of primary origin or derived from a pre-existing silicate, is found in association with minerals as different as pyrite and hematite, so it is clearly a stable mineral over a wide range of oxidation-reduction conditions. Sulphides are very likely present in the Schapenburg iron-formations as indicated by gossanous zones of brightly coloured ochres (limonite, goethite and hematite).

The cyclical volcanism and sedimentation in the greenstone belt suggests that mafic and ultramafic magmas were extruded in pulses in a subaqueous (presumably relatively deep water) environment where conditions were suitable for chemical sedimentation to follow each successive eruptive event. This may have occurred in some submarine canyon that was environmentally somewhat better protected than, for example, the Komati Formation type area in the Barberton greenstone belt, where flow after flow of mafic and ultramafic magma rapidly built up a volcanic pile within which no sedimentary rocks of the iron-formation type could develop.

3. *Metasediments*

Almost all the greenstone remnants flanking the Barberton greenstone belt are comprised dominantly of metamorphosed mafic or ultramafic volcanic rocks. Metasedimentary rocks are generally rare or subordinate components and usually consist of banded iron-formation (usually oxide facies), banded ferruginous cherts, carbonaceous cherts, and banded black, white, green or grey cherts (Anhaeusser, 1980; Menell *et al.*, 1981; Robb, 1977). Many of the sedimentary components are also of volcanogenic origin and include reworked pyroclastic rocks (including agglomerates, lapilli tuffs and tuffs). A small proportion of the metasediments also include a variety of calc-silicate rocks, some units of which occur in the greenstone remnants south-east of Badplaas (Fig. 1) in the area surrounding the Boesmanskop syenite pluton (Anhaeusser and Robb, 1980; Viljoen and Viljoen, 1969a).

Many of the lithologies mentioned above were also encountered in the Schapenburg belt. In addition, however, there exists what appears to be a unique development (at least as far as the xenoliths in the Barberton Mountain Land are concerned) of metasediments, including metagreywackes and metapelites with subordinate calc-silicate interlayers and metamorphosed chert. These rocks occupy a zone approximately 500 m wide on the south-western side of the farm Klipplaatdrift 179 IT (Fig. 2, B1). This metasedimentary unit is then faulted westwards in successive blocks and the sequence extends onto the farm Schapenburg 178 IT in the vicinity of the nose of the tonalite body separating the east and west limbs of the greenstone remnant (Fig. 2, B2, B3). Here the metasedimentary zone thins progressively northwards from approximately 300 m wide near sample locality JV 24, to a thin sliver in the Theespruit river valley. The southern limit of the metasedimentary unit is not known as the rocks extend into the Jessievale forests and are not exposed.

From east to west, across the best developed sequence on the farm Klipplaatdrift 179 IT (Fig. 2, B1), the metasediments include a zone of recrystallized white-to-buff-coloured *chert*, the latter being approximately 30-40 m wide and dipping between 75-85^{o} east. Due to recrystallization the chert has the appearance of a quartzite and is as friable as a sandstone in places where the rock have been weathered. Thin sections examined revealed only sutured quartz crystals and minor amounts of sericite.

West of the chert unit is a wide zone of variably exposed metagreywackes and intercalated calc-silicate units as well as what appears to be a single lava flow surrounded by the metasediments. The lava flow (metabasalt) has, like the nearby chert and other rocks in the area, been metamorphosed and has a fine-grained, hornfelsic appearance. Mineralogically it consists of actinolite, chlorite, sodic plagioclase, quartz, and accessory sphene. A chemical analysis of the rock (sample JV 12A, Fig. 2, B1) is listed in Table 1, column 6, and has the characteristics of a basaltic komatiite of the Barberton-type (± 10% MgO) as defined by Viljoen and Viljoen (1969a).

The *metagreywackes* and *metapelites* are best exposed in a stream section in the vicinity of the meta-basalt unit described above. The outcrops reveal a continous sequence of steeply dipping (subvertical), parallel laminated, strata (Plate 2B and 2C) typically like the turbidite deposits described by Bouma (1962) and Dzulynski and Walton (1965). The outcrops show repetitive greywacke sandstones and shales and are black to dark grey where fresh. The succession displays graded laminated bedding varying from a few millimetres to about 5 cm in width with little variation. Bedding plane slippage and flattening of the successions probably distorts the original character of the sediments. Anatectic melting of the greywackes is seen in places (Plate 2B and 2C) and the anatectic veins have themselves been boudinaged and attenuated by the flattening deformation.

A detailed study of the Schapenburg metagreywackes is being undertaken (Anhaeusser - in prep.) but preliminary investigations indicate that a wide range of metamorphic minerals are present in the rocks. In some units almandine garnets are prolifically developed and in others they are virtually absent. The main amphibole is grunerite with subordinate hornblende/actinolite. Quartz, biotite, and magnetite occur prominantly and plagioclase, microcline, chlorite and apatite were noted in some specimens. In some places the metagreywackes display nodular, positively weathered crystals of andalusite (Plate 2D) together with cordierite, almandine, biotite, quartz and magnetite. Some staurolite is also present and the andalusite and cordierite show signs of retrogression to pyrophyllite and sericite. In places the metasediments are phyllitic or even schistose with the phyllosilicate and amphibole constituents of the rocks strongly aligned parallel to the bedding or schistosity planes. The garnet, andalusite and cordierite porphyroblasts are generally poikilitic and often show pressure shadows, crystal rotation and boudinage structures. Nodular structures, such as those illustrated in Plate 2E, are possibly the result of metamorphism, but may also be relic sedimentary structures such as conical or linguiform flute moulds like those typically produced in the turbulent zones near the point of discharge of turbidity currents (Dzulynski and Walton, 1965).

Chemical analyses of two samples of metagreywacke are listed in Table 1, columns 7 and 8. Sample JV 12 contains abundant magnetite, together with quartz, grunerite and numerous poikilitic garnets. Sample JV 14, by contrast, has considerably less magnetite and contains lensoid cordierite porphyroblasts (the latter full of inclusions), together with biotite, quartz, grunerite, andalusite, staurolite, chlorite, apatite and some tourmaline. The garnet porphyroblasts are poikilitic and apparently late in the paragenesis as the crystals grow across the earlier-formed cordierite-biotite-grunerite-andalusite mineral trends.

Less common than than the metagreywackes, but nevertheless forming distinctive units within them (Fig. 2, B1, B2), are the *calc-silicate rocks* that occur in zones up to 10 m wide in places. These calc-silicate units outcrop as distinctive, differentially weathered, ridges interlayered with the metagreywackes, and form useful marker beds traceable over long distances. In the field the rocks are generally light coloured (greenish white to buff coloured), and contrast clearly with the surrounding dark-grey metagreywackes.

Petrologically, these rocks contain a range of minerals that occur in various combinations. These include diopside, hornblende, actinolite, tremolite, plagioclase, microcline, quartz, carbonate, epidote, and chlorite, together with accessory amounts of magnetite, garnet, sphene and sericite. This wide ranging mineralogy is reflected in the compositional differences encountered in these rocks. This is illistrated in Table 1, columns 9 and 10, where marked differences are evident between all elements listed. Sample JV 24 contains mainly quartz, microcline and diopside with lesser amounts of tremolite, epidote, and sphene. Sample JV 30,which has less SiO_2, Al_2O_3, Na_2O and K_2O,contains no microcline but instead has some plagioclase. The higher total iron, MgO and CaO is due to the presence of magnetite, and abundant diopside and tremolite. Some carbonate, epidote and sphene is also present.

The original nature of the calc-silicate rocks found in the greenstone xenoliths of the Barberton Mountain Land remains obscure. As these rocks generally form part of the Sandspruit or Theespruit formations at the base of the Onverwacht volcanic pile they are invariably metamorphosed by the trondhjemitic gneisses that intrude and fragment the greenstone successions. From their mineralogy, however, it is believed that the calc-silicate rocks originally comprised pelagic calcareous marls with very large ranges in compositions. These sediments appear to have accumulated mainly betwen stages of volcanism and, in the case of the Schapenburg occurrences, between episodes triggering turbidity current sedimentation of greywackes and shales.

C. Granitic Rocks

Earlier it was shown that the Schapenburg greenstone remnant is enveloped by a variety of granitic rock types that fall into one or other of the three magmatic cycles defined for the region by Anhaeusser and Robb (1981), and further discussed by Anhaeusser and Robb (1982), Robb (1981a,b,c, 1982), Robb and Anhaeusser (1982) and Robb *et al.*, (1982). In the area shown in Fig. 2, and for the purpose of description here, the granitic rocks are divisible into four distinctive categories. These, in turn, form components of the first and second magmatic cycles.

1. *Trondhjemitic Gneisses and Migmatites*

Leuco-biotite trondhjemitic or tonalitic gneisses occur in regions immediately flanking the Schapenburg greenstone successions but are particularly prominent along the lower reaches of the Theespruit valley on the farms Schapenburg 178 IT and Welgevonden 175 IT (Fig. 2, B5 - B7). The gneisses are strongly foliated parallel to the greenstone contacts and contain numerous mafic xenoliths and migmatitic zones, the latter formed as a result of granite-greenstone interaction (Anhaeusser and Robb, 1980; Robb, 1981b, 1982).

The trondhjemitic gneisses consist essentially of quartz, sodic plagioclase (albite-oligoclase) and biotite, together with lesser amounts of microcline, sphene, apatite, magnetite and zircon. A chemical analysis of a typical trondhjemitic gneiss from the area is listed in Table 1, column 11.

2. *Granodioritic Gneisses and Migmatites*

Outwards, away from the greenstone contacts, the trondhjemitic gneisses and migmatites, which form part of the assemblage typical of first magmatic cycle, appear to be influenced by the later potassic batholiths described earlier. This is manifest by a progressive increase in the amount of pinkish coloured potash feldspar evident in the gneisses and migmatites as well as by the increased presence of pegmatite veins and stringers. In some cases the pink gneisses occur in juxtaposition with the greenstones, as for example at localities JV 7 (Fig. 2, B2), JV 34 (Fig. 2, B5), and ET 7 (Fig. 2, C 7).

Mineralogically, the pink or pinkish-grey gneisses contain prominent amounts of microcline which replaces the sodic plagioclase in the trondhjemites. Chemical analyses of these rocks, which are essentially granodioritic gneisses, are listed in Table 1, columns 16-18. Apart from notable differences in certain major elements, particularly the alkali elements, the granodioritic gneisses show marked variations in the Rb, Sr, and Ba contents when compared with the trondhjemite gneisses. In terms of the granite classification scheme of Anhaeusser and Robb (1981) the granodioritic gneisses (including in places potassic migmatites) constitute part of the marginal K-rich migmatite zones typically found rimming the second magmatic cycle batholiths. These migmatites, in turn, pass gradationally into the coarse-grained, homogeneous, porphyritic, adamellites and granodiorites that form the dominant components of the batholiths (Anhaeusser and Robb, 1982; Robb *et al.*, 1982).

3. *Tonalitic Gneisses*

The central granitic tongue separating the east and west limbs of the Schapenburg greenstone belt consists essentially of a medium-to-fine-grained tonalite gneiss body which outcrops prominently in the vicinity of the Klipplaatdrift-Schapenburg farm boundary (Plate 1D). In addition to the main pluton there are a number of smaller tonalite bodies intruded into the greenstone successions to the south. These include pods and dyke-like occurrences of tonalite in the metabasalts and metasediments near sample locality JV 24 (Fig. 2, B2) as well as a narrow, elongate tonalite body near sample site JV 2 (Fig. 2, B1).

The main tonalite body consists of hornblende-biotite gneiss. In places the rocks are relatively homogeneous and only weakly foliated. Numerous mafic inclusions, thought to be xenoliths of the Schapenburg greenstone belt, occur in the body and show various stages of assimilation or metasomatic alteration (Plage 2F). In places the greenstone xenoliths are irregularly-shaped and randomly orientated whereas elsewhere, particularly where the foliation in the gneisses is strongly developed,the xenoliths or mafic schlieren are lens -shaped and generally aligned parallel to the gneissocity. The southern contacts with the greenstone belt are sharp and relatively well-defined but the north-eastern extension of the body appears to be gradational into the granodiorites and adamellites developed in the southern part of the farm Welgevonden 175 IT.

Mineralogically, the main tonalitic body consists of poikilitic hornblende (the latter showing various degrees of alteration to a khaki-green or brown biotite, chlorite, zoned sericitized sodic plagioclase (albite), microcline, quartz, magnetite and sphene. In places the tonalite is mesocratic while in others, particularly where there are numerous mafic inclusions, it is melanocratic. The greenstone xenoliths typically consist of hornblende (the latter variably altered to green biotite), quartz, apatite, sphene, magnetite and some plagioclase feldspar (porphyroblasts, megacrysts). Sample JV 2 from one of the smaller intrusive bodies contains abundant quartz, sericitized albite,and chlorite. Less prominent are muscovite, magnetite, microcline, and sphene.

Chemical analyses of the various tonalite gneisses described above are listed in Table 1, columns 12-15. They differ from the previously described trondhjemitic gneisses in respect of their lower SiO_2 contents. In addition,all the remaining major elements as well as the trace elements Rb, Sr, and Ba exceed their trondhjemitic counterparts. No isotopic data is available from this granitic suite and it is not certain whether these rocks form part of the first magmatic cycle (the preferred interpretation) or whether they represent some younger event.

4. *Homogeneous Granodiorites and Adamellites*

Pinkish or pinkish-grey, medium-to-fine-grained, homogeneous granodiorites and adamellites occupy the high lying ground both east and west of the Schapenburg greenstone belt (Fig. 2 and Plate 1C). These rocks, as has been outlined earlier, form part of the Heerenveen and Mpuluzi batholiths west and east, respectively, of the greenstone remnant (Anhaeusser and Robb, 1982).

In places the adamellites/granodiorites are weakly foliated, as in the areas close to the greenstone belt margins. Elsewhere there may be isolated nebulitic remnants present but mostly these rocks are even-textured, homogeneous-to-porphyritic massifs occupying large tracts and building the elevated, plateau-like region east, west and south of the Jessievale-Schapenburg area.

Mineralogically, these rocks consist mainly of quartz, microcline and plagioclase (albite). Perthite, microcline perthite and myrmekite are common constituents and occur together with lesser amounts of sericite, chlorite, biotite, epidote, muscovite, apatite, magnetite, sphene and even some carbonate in places. Microcline megacrysts, or phenocrysts, are not uncommon and generally contain inclusions of quartz and plagioclase, indicating a late paragenesis.

Chemically, the rocks are distinguished by their relatively high total alkalis, particularly K_2O, and their low ferromagnesian content. By contrast with the tonalites and trondhjemites, these potash-rich granites, which are grouped into the second magmatic cycle (Anhaeusser and Robb, 1981), also have high Rb and low Sr contents (Table 1, columns 19 and 20).

D. Mafic Dykes

Several varieties of mafic dykes occur within the area shown in Fig. 2. The oldest dyke encountered is a coarse-crystalline, amphibolite dyke, the latter entirely surrounded by trondhjemitic gneisses on the farm Schapenburg 178 IT (Fig. 2, A4). This dyke, which is black in colour, contains large pyroxene (augite) crystals altered partly or totally to green hornblende or actinolite. The rock also contains some quartz, plagioclase (albite), sericite, sphene, apatite, magnetite, and some epidote. The dyke was presumably emplaced into the trondhjemitic gneisses and was subsequently metamorphosed by the intrusion of the granites of the Heerenveen batholith nearby.

The remaining dykes in the area are mainly diabases, including porphyritic diabases, gabbros, and dykes containing inclusions of granitic rocks through which, or into which, the dykes were emplaced. These, as was explained earlier, form part of a regional NW-SE dyke swarm believed to be of Proterozoic or younger age.

IV. STRUCTURE

Two aspects of the structure in the map area warrant mention. The first concerns the Schapenburg greenstone belt which, apart from the regional flattening event responsible for the development of the schistosity seen throughout the area, is surprisingly undisturbed by tectonic influences. The deformation seen in the area was probably initiated when the greenstones were first invaded by the trondhjemitic gneisses approximately 3,400 Ma ago. This resulted in the deep infolding of the well-layered stratigraphic succession and the subsequent lit-par-lit invasion of the subvertical strata by the intrusive trondhjemites. The central tonalite tongue responsible for splitting the belt into two limbs may represent an anatectic body produced by the melting of the deeply infolded volcano-sedimentary succession during this early stage of deformation. Isoclinal folding may exist in the belt but no confirmatory evidence was found. Facing indicators across the belt appear to be consistent with a younging direction from west to east.

The emplacement of the Heerenveen and Mpuluzi batholiths appears to have played a minor role in the deformation of the greenstone belt. Regional evidence suggests that the batholiths were emplaced relatively passively with the marginal migmatite zones inheriting the tectonic and other characteristics of the granite-greenstone terrane created during the first magmatic cycle (Anhaeusser and Robb, 1982).

The second noteworthy structural aspect concerns the regional faulting and fracturing responsible for slicing the map area into numerous segments. These faults strike NW-SE and some can be traced for over 100 km from northern Natal and Swaziland westwards to the Transvaal Drakensberg escarpment and beyond (Anhaeusser - in prep.). Their regional character is best observed on aerial photographs or Landsat images. In the field many of these faults are represented by zones of disturbance only a few metres wide. Some fractures are occupied by mylonite zones only a few centimetres wide and many are intruded by dykes. If the dykes are of Proterozoic age then the fractures are probably of the same age or older. What precisely was responsible for the fracturing remains uncertain but it was clearly related to some regional tectonic condition of subcratonic dimensions. Faults not replaced by dykes are sometimes filled with white vein quartz whereas others are manifest merely as a zone of sheared and sericitized granites. The faults and fractures also influence the regional drainage pattern and many linear tributaries occur on the batholiths.

V. METAMORPHISM

In earlier sections mention was made of the metamorphic mineral assemblages found in the volcanic and sedimentary rocks making up the Schapenburg greenstone belt. In general terms these metamorphic assemblages equate with those typifying the Abukuma-type facies series as defined by Winkler (1967). This facies series includes the greenschist and amphibolite grades and are characterized by metamorphism resulting from low-pressures (± 10 km depths or 3-3,5 kb) and temperatures of approximately 700°C. These metamorphic facies have now largely been supplanted by the recent usage of the terms low grade and medium grade, respectively, for the greenschist and amphibolite facies (Winkler, 1974).

The mafic and ultramafic rocks that predominate in the Schapenburg greenstone belt mainly contain actinolite or chlorite which coexist with albite, quartz and some zoisite/epidote. These are typical low-grade (greenschist) assemblages that pass into medium-grade amphibolites containing hornblende, zoisite/epidote, almandine garnet, quartz, and chlorite, in areas situated closer to granitic contacts. Confirmatory evidence of low-or- medium-grade metamorphism is afforded by the metasedimentary rocks found in the belt. The presence in the metagreywackes or metapelites of garnet (almandine), andalusite, grunerite, cordierite, biotite, and quartz suggests that their formation took place in the higher temperature part of low-grade metamorphism (Winkler, 1974). The presence of cordierite ± staurolite further suggests that temperatures may have been in the range 505-565°C, depending upon P_{H_2O}. These temperatures may have been exceeded in places, resulting in incipient anatexis of the metasediments. According to Winkler (1967, 1974) temperatures required for anatexis of metagreywackes can range from 700°C (at P_{H_2O} = 2000 bars) to 680°C (P_{H_2O} = 4000 bars). At higher water pressures these temperatures can be even lower.

In summary, therefore, it appears that the temperatures attained in the Schapenburg greenstone belt may have ranged from approximately 500-700°C depending upon proximity to some of the intrusive granites developed in the area. Pressures appear to have been low and probably ranged between 2500 to 3500 bars — pressures akin to regional metamorphism or localized contact metamorphism associated with low-to-medium metamorphic grades of Winkler (1974).

VI. ECONOMIC GEOLOGY

No mines or mineral prospects exist in the Schapenburg greenstone belt or surrounding granitic terrane. However, during the field mapping a number of gossanous zones were encountered, particularly in association with the ferruginous banded cherty iron-formations. Five samples taken from a gossanous banded iron-formation approximately midway between samples JV 23 and JV 38 (Fig. 2, B2 and B3) yielded the results listed in Table II. These samples consisted of banded limonitic gossans with shiny and duller bands of gossan alternating with siliceous cherty bands. A second set of samples was collected from a siliceous zone in the metabasalts located approximately 750 m north-east of sample JV 27 (Fig. 2, A3). Red limonitic gossan, finely banded in places, occurs here in a massive quartz-rich zone containing sulphides (mainly pyrite). Analyses from these samples are also listed in Table II. No follow up investigations of the economic potential of the gossans was undertaken.

TABLE 2

TRACE ELEMENT ANALYSES OF GOSSANOUS SAMPLES FROM THE SCHAPENBURG GREENSTONE REMNANT

Sample No.		Cu ppm	Pb ppm	Zn ppm	Ni ppm
JV 5	A.	250	10	270	170
	B.	180	10	230	150
	C.	220	10	235	160
	D.	200	10	130	470
	E.	440	10	180	180
JV 29	A.	150	10	30	100
	B.	160	10	40	130
	C.	170	10	40	10
	D.	100	20	35	10

Analysts: Johannesburg Consolidated Investment Co. Limited

Samples JV 5A-E. Gossanous silicate facies banded iron-formation, east limb of Schapenburg greenstone belt.

Samples JV 29 A-D. Gossanous siliceous zone in metabasalts, west limb of Schapenburg greenstone belt.

VII. SUMMARY AND CONCLUSIONS

The principal features of the Archaean granite-greenstone terrane in the vicinity of the Schapenburg volcano-sedimentary remnant may be summarized as follows:

1. The Schapenburg greenstone belt is one of a number of xenoliths that can be traced southwards for over 60 km from the main body of the Barberton greenstone belt. It represents a fragment of the basal portion of the Onverwacht volcanic pile (Tjakastad Subgroup) and is made up principally of komatiitic metabasalts and meta-peridotitic lava flows, the latter containing well-preserved spinifex textures in places.

2. The mafic and ultramafic metavolcanic units are frequently accompanied by interlayers of silicate facies banded iron-formation and together these rocks form a regular, cyclically layered, volcano-sedimentary pile. Ideally, each cycle consists of peridotite overlain by basalt, the latter capped by banded iron-formation. In some cycles the banded iron-formation, which generally consists of a banded grunerite-chert rock, is absent or only poorly developed. The peridotites are generally serpentinized but relic olivine was encountered in some zones where spinifex textures are still preserved, and in coarse-grained cumulate-textured harzburgite zones found at the base of some of the thicker flow units. The metabasalts are generally altered to a wide variety of mafic schists (hornblende-actinolite-chlorite schists).

3. The mafic and ultramafic flows may be equated with similar units described in the Komati Formation type locality (Viljoen and Viljoen, 1969a,c; Viljoen *et al.*, 1982). Despite textural evidence as well as consistent pillow facing directions the view has been expressed (de Wit and Stern, 1980) that the successions in the Komati Formation are not flows but rather represent sheeted dykes forming part of an Archaean ophiolite complex. The absence of interlayered sediments within the spinifex-textured peridotite and pillow basalt succession was cited in support of an intrusive, as opposed to an extrusive, origin for the Komati Formation type sequence. The Schapenburg volcano-sedimentary cyclicity therefore has some bearing on the interpretations that can be placed on the evolution of the Barberton volcanic pile — this despite being removed from the immediate vicinity of the area whose origin is in dispute.

4. The Schapenburg greenstone belt contains a unique (i.e. for the Barberton region) development of metasediments comprising metagreywackes, metapelites, and calc-silicate rocks. These assemblages represent metamorphosed turbidites and calcareous pelagic marls. The restricted occurrence of the greywackes, as opposed to the calc-silicate rocks which are also developed in other greenstone remnants in the region, suggests they probably formed in a deep submarine canyon following turbidity flow action.

5. The metagreywackes display a wide range of metamorphic minerals, including mainly grunerite ± almandine ± cordierite ± andalusite ± staurolite + biotite + quartz + magnetite, and incipient anatectic melting of the sediments is apparent in places. The calc-silicate rocks contain mainly diopside ± garnet ± microcline ± tremolite ± zoisite/epidote ± albite ± magnetite + quartz.

These metamorphic mineral assemblages are indicative of low-to-medium grades of metamorphism (Winkler, 1974) and coincide with the low pressure-high temperature Abukuma facies series of Winkler (1967). The rocks in the Schapenburg greenstone remnant were thus probably affected by temperatures ranging from 500-700°C, depending upon their position relative to the intrusive granites, and pressures ranging between 2500-3500 bars.

6. The greenstone belt is intruded by a variety of granitic rock types including foliated leuco-biotite trondhjemitic or tonalitic gneisses (≅3500-3200 Ma old) and massive, homogeneous, granodiorites and adamellites (3200-3000 Ma old). The trondhjemite/tonalite gneisses are also associated with complex migmatites produced mainly as a result of granite-greenstone interaction and all together form components of the *first magmatic cycle* of Archaean granites as defined by Anhaeusser and Robb (1981). The granodiorites and adamellites represent components of the Heerenveen and Mpuluzi batholiths which occur on the west and east flanks, respectively, of the Schapenburg greenstone belt and which also display marginal K-rich migmatites and gneisses in areas rimming the batholiths or in close contact with the greenstone xenoliths. These potassic granites constitute part of the *second magmatic cycle* of granitic activity in the Barberton Mountain Land.

7. Structurally, the Schapenburg greenstone belt is divided into an east and a west limb separated by an intrusive tongue of hornblende-biotite tonalite. The greenstone successions dip subvertically and strike north-east forming regular units that can be traced for many kilometres. This regularity is disturbed only by a number of north-west-striking faults and fractures as well as a diabase dyke swarm which segments the belt and causes left lateral strike separation of the formations. The faulting and associated dyke intrusion probably commenced during the late Archaean but most likely reached a peak during early or middle Proterozoic times.

8. No mineral deposits are known in the greenstone belt or in the surrounding granitic terrane. However, a number of gossanous zones were noted, the latter being mainly associated with the silicate facies banded iron-formations capping the mafic-ultramafic volcanic cycles developed throughout the Schapenburg belt. The iron-formation units are probably a manifestation of fumarolic exhalative sedimentation in a dominantly volcanogenic regime and hence could be regarded as possible host rocks for a wide variety of mineral species, including gold.

ACKNOWLEDGMENTS

The writer wishes to thank Drs. L.J. Robb and M.J. Viljoen for their critical reading of the manuscript and for their constructive criticism of various aspects of the study. Mrs. W. Job and Mr. N.A. de N.C. Gomes are thanked for their draughting assistance. Mrs. D. Amaler and Mrs. L. Tyler kindly typed draft and final copies of the manuscript.

REFERENCES

Anhaeusser, C.R. (1971). Cyclic volcanicity and sedimentation in the evolutionary development of Archaean greenstone belts of shield areas. *Spec. Publ. geol. Soc. Aust.*, 3, 57-70

Anhaeusser, C.R. (1980). A geological investigation of the Archaean granite-greenstone terrane south of the Boesmanskop syenite pluton, Barberton Mountain Land. *Trans. geol. Soc. S. Afr.*, 83, 73-106.

Anhaeusser, C.R., and Robb, L.J. (1981). Magmatic cycles and the evolution of the Archaean granitic crust in the Eastern Transvaal and Swaziland. *Spec. Publ. geol. Soc. Aust.*, (in press).

Anhaeusser, C.R. (1982). Geological and geochemical characteristics of ultramafic flow units in the Schapenburg greenstone remnant, Barberton Mountain Land. (in preparation).

Anhaeusser, C.R., and Robb, L.J. (1980). Regional and detailed field and geochemical studies of Archaean trondhjemite gneisses, migmatites and greenstone xenoliths in the southern part of the Barberton Mountain Land, South Africa. *Precambrian Res.*, 11, 373-397.

Anhaeusser, C.R., and Robb, L.J. (1982). Geological and geochemical characteristics of the Heerenveen and Mpuluzi batholiths south of the Barberton greenstone belt and preliminary thoughts on their petrogenesis. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Anhaeusser, C.R., Robb, L.J., and Barton, J.M. Jr (1982). Mineralogy, petrology and origin of the Boesmanskop syeno-granitic complex, Barberton Mountain Land, South Africa. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Ayres, L.D. (1977). Importance of stratigraphy in early Precambrian volcanic terranes : cyclic volcanism at Setting Net Lake, Northwestern Ontario. *Spec. Pap. geol. Assoc. Can.*, 16, 243-264.

Baragar, W.R.A., and Goodwin, A.M. (1969). Andesites and Archean volcanism of the Canadian Shield, 121-142- In: *Proc. Andesite Congr.* (Eugene and Bend, Oregon, 1968), *Bull. Oregon Dept. Geol. Mineral Indust.*, 65.

Barton, J.M., Jr. (1981). The pattern of Archaean crustal evolution for southern Africa as deduced from the evolution of the Limpopo Mobile Belt and the Barberton granite-greenstone terrane. *Spec. Publ. geol. Soc. Aust.*, 7, (in press).

Barton, J.M.,Jr. (1982). Isotopic constraints on possible tectonic models for crustal evolution in the Barberton granite-greenstone terrane, southern Africa. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Barton, J.M., Jr., Robb, L.J., Anhaeusser, C.R., and van Nierop, D.A. (1982). Geochronologic and Sr-isotopic studies of certain units in the Barberton granite-greenstone terrane, South Africa. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Bouma, A.H. (1962). *Sedimentology of Some Flysch Deposits — a Graphic Approach to Facies Interpretation.* Elsevier, Amsterdam, 168 pp.

de Wit, M.J., and Stern, C.R. (1980). A 3500 Ma ophiolite complex from the Barberton greenstone belt, South Africa : Archaean oceanic crust and its geotectonic implications. *Extended Abstr., 2nd Int. Archaean Symp., Perth, 1980. Geol. Soc. Aust.*, 85-87.

Dzulynski, S., and Walton, E.K. (1965). *Sedimentary Features of Flysch and Greywackes.* Developments in Sedimentology, 7, Elsevier, Amsterdam, 274 pp.

Glikson, A.Y. (1976). Stratigraphy and evolution of primary and secondary greenstones : significance of data from shields of the southern hemisphere, 257-277. In : Windley, B.F. Ed., *The Early History of the Earth*, Wiley, London, 619 pp.

Goodwin, A.M. (1977). Archean volcanism in Superior Province, Canadian Shield. *Spec. Pap. geol. Assoc. Can.*, 16, 205-241.

Hamilton, P.J., Evensen, N.M., O'nions, R.K., Smith, H.S., and Erlank, A.J. (1979). Sm-Nd dating of Onverwacht Group volcanics, southern Africa. *Nature*, 179, 298-300.

Hunter, D.R. (1974). Crustal development in the Kaapvaal craton, I. The Archaean. *Precambrian Res.*, 1, 259-294.

James, H.L. (1954). Sedimentary facies of iron-formation. *Econ. Geol.*, 49, 235-293.

Menell, R.P., Brewer, T.H., Delve, J.R., and Anhaeusser, C.R. (1981). The geology of the Kalkkloof chrysotile asbestos deposit and surrounding area, Barberton Mountain Land. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand*, 154, 10 pp.

Oosthuyzen, E.J. (1970). *The geochronology of a suite of rocks from the granite terrain surrounding the Barberton Mountain Land.* Ph.D. thesis (unpubl.), Univ. Witwatersrand, Johannesburg.

Pyke, D.R., Naldrett, A.J., and Eckstrand, O.R. (1973). Archean ultramafic flows in Munro Township, Ontario. *Bull. geol. Soc. Amer.*, 84, 955-978.

Robb, L.J. (1977). *The geology and geochemistry of the Archaean granite-greenstone terrane between Nelspruit and Bushbuckridge, Eastern Transvaal.* M.Sc. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 190 pp.

Robb, L.J. (1981a). Detailed studies of select migmatite outcrops in the region southwest of the Barberton greenstone belt and their significance concerning the nature of the early Archaean crust in the region. *Spec. Publ. geol. Soc. Aust.*, (in press).

Robb, L.J. (1981b). *The geological and geochemical evolution of tonalite-trondhjemite gneisses and migmatites in the Barberton region, eastern Transvaal.* Ph.D. thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 342 pp.

Robb, L.J. (1981c). Geological and chemical characteristics of the late granite plutons in the Barberton region and Swaziland with an emphasis on the Dalmein pluton — a review. *Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg*, 157, 16 pp.

Robb, L.J. (1982). The nature, origin and significance of Archaean migmatites in the Barberton Mountain Land; a new approach in the assessment of early crustal evolution. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Robb, L.J., and Anhaeusser, C.R. (1982). Chemical and petrogenetic characteristics of Archaean tonalite-trondhjemite gneiss plutons in the Barberton Mountain Land. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Robb, L.J., Anhaeusser, C.R., and van Nierop, D.A. (1982). The recognition of the Nelspruit batholith north of the Barberton greenstone belt and its significance in terms of Archaean crustal evolution. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Smith, H.S. (1980). *Aspects of the geochemistry of Onverwacht Group lavas from the Barberton greenstone belt.* Ph.D. thesis (unpubl.), Univ. Cape Town, 253 pp.

Viljoen, M.J., and Viljoen, R.P. (1969a). 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.

Viljoen, M.J., and Viljoen, R.P. (1969b). A proposed new classification of the granitic rocks of the Barberton region. *Spec. Publ. geol. Soc. S. Afr.*, 2, 153-180.

Viljoen, M.J., and Viljoen, R.P. (1969c). Evidence for the existence of a mobile extrusive peridotitic magma from the Komati Formation of the Onverwacht Group. *Spec. Publ. geol. Soc. S. Afr.*, 2, 87-112.

Viljoen, R.P., and Viljoen, M.J. (1969d). The geological and geochemical significance of the upper formations of the Onverwacht Group. *Spec. Publ. geol. Soc. S. Afr.*, 2, 113-151.

Viljoen, M.J., Viljoen, R.P., Smith, H.S., and Erlank, A.J. (1982). Geological, textural and geochemical features of peridotitic and basaltic komatiite flows from the Komati Formation. *Spec. Publ. geol. Soc. S. Afr.*, (in press).

Visser, D.J.L., Compiler (1956). The geology of the Barberton area. *Spec. Publ. geol. Surv. S. Afr.*, 15, 253 pp.

Winkler, H.G.F. (1967). *Petrogenesis of Metamorphic Rocks.* 2nd Ed., Springer-Verlag, New York, 237 pp.

Winkler, H.G.F. (1974). *Petrogenesis of Metamorphic Rocks.* 3rd Ed., Springer-Verlag, New York, 320 pp.

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Figure 2 : *Geological map of the Schapenburg greenstone remnant and surrounding granitic terrane, Barberton Mountain Land.*

PLATE 1

A. View looking east, from the low-lying trondhjemite gneiss and migmatite terrane of the Theespruit River valley, towards the topographically high, northern marginal zone of the potash-rich Mpuluzi batholith. On the slopes below the granitic cliffs are zones of potassic migmatite and greenstone remnants linking the Schapenburg schist belt with that of the Weergevonden schist belt to the left of the photograph.

B. Differentially weathered mafic and ultramafic schist ridges and long narrow troughs on the south-eastern flank of the Schapenburg greenstone remnant on the farm Klipplaatdrift 179 IT. In the background are the domical cliffs forming the marginal zone of the Mpuluzi batholith and the afforested granitic plateau, the latter transected by numerous, predominantly north-west-trending diabase dykes and fractures.

C. Granitic rocks of the Heerenveen batholith forming part of a high-level (± 1700 m) plateau (in the foreground) beyond which is the deeply incized valley on the western flank of the prominently-layered Schapenburg schist belt. In the background is the elevated terrain forming part of the Mpuluzi batholith.

D. View of part of the eastern limb of the Schapenburg greenstone belt on the farm Klipplaatdrift 179 IT. In the foreground are outcrops of the medium-to-fine-grained tonalite body that intrudes the central portion of the belt on the farm Schapenburg 178 IT (Fig. 2). The greenstone succession shown comprises regular, cyclically developed, ridges of serpentinized ultramafic rocks and intervening, smooth, grass-covered, areas underlain by amphibole-chlorite-talc schists and interlayered banded iron-formations. Sample JV 23 was collected from the most prominent ultramafic ridge see beyond the landrover.

E. Photograph showing portion of the upper part of an ultramafic flow unit near sample locality JV 40 (Fig. 2, B2). Differential weathering highlights the long, bladed- or plate-like crystals of olivine which form the lower part of the spinifex zone, and are sharply gradational with overlying fine-bladed, random spinifex (right of the hammer head). This passes upwards into a chilled and fractured flow top.

F. View looking north-east, on the farm Klipplaatdrift 179 IT, showing the nature of the volcano-sedimentary cycles developed in the area. The succession appears to young from west to east (left to right) across the photograph. The smooth slope (top left) comprises schistose metabasalt overlain by a thin-banded silicate facies iron-formation. This, in turn, is overlain by a serpentinized peridotite ridge (base of cycle), more metabasalt (smooth slopes), followed by a banded iron-formation at the top of the cycle (scree covered slope left of dark bush). The serpentinized peridotite of the next cycle commences at the dark bush and forms the boulder strewn ridge on the right. In the foreground are outcrops of banded iron-formation at the top of the central cycle.

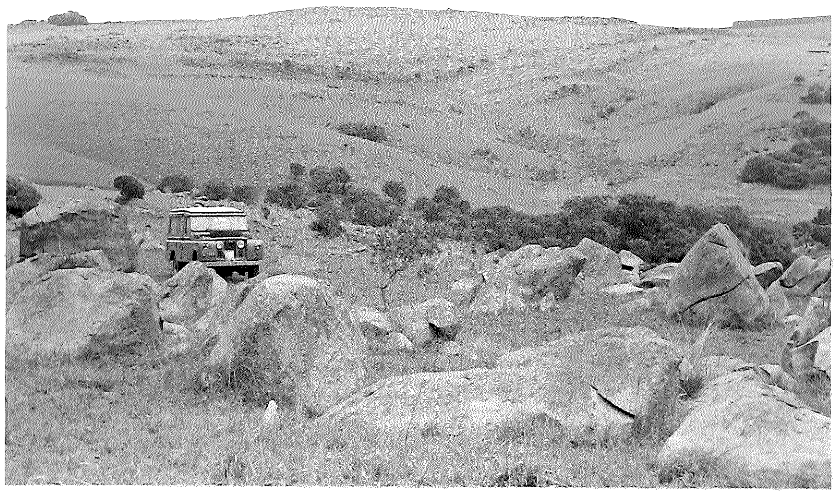
PLATE I

A

B

C

D



E

F

PLATE 2

A. Banded silicate facies iron-formation east of sample JV 4 (Fig. 2, B2). The recrystallized chert bands can seldom be traced for more than a few metres before they either lens out or are boudinaged along strike. The silicate component of the rocks consists mainly of grunerite ± hornblende ± actinolite ± chlorite, together with quartz and magnetite.

B. Subvertical, parallel laminated, metagreywackes and shales exposed in a river section on the farm Klipplaatdrift 179 IT (Fig. 2, B1). The sediments show graded bedding but have been recrystallized and contain mineral assemblages consisting mainly of grunerite ± almandine ± cordierite ± andalusite ± biotite + quartz + magnetite. The metamorphism caused partial melting of the sediments as is witnessed by the boudinaged anatectic veins developed parallel to the bedding.

C. Graded laminated bedding in metagreywackes and shales from the same locality as Plate 2B. Boudinaged anatectic veins are developed parallel to the rhythmically layered sediments which were probably deposited by turbidity flows. The recrystallization of the sediments makes the determination of facing directions ambiguous.

D. Megacrysts of andalusite (beneath hammer) developed in the contact metamorphic aureole of a small tonalite body intruded into the Schapenburg greenstone belt near sample locality JV 2 (Fig. 2, B1). The flattened metagreywackes on the right contain nodules of cordierite together with variable amounts of andalusite, biotite, almandine, staurolite, grunerite, magnetite and quartz.

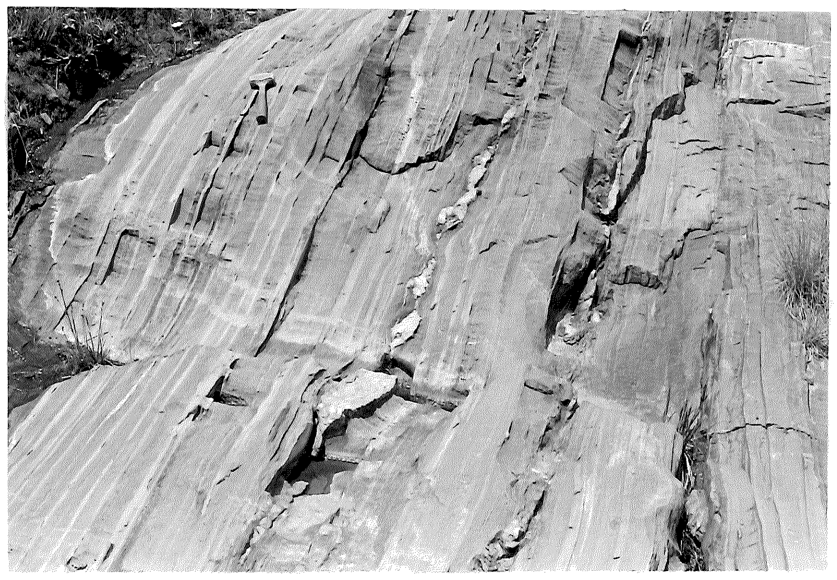
E. Nodular structures in metagreywackes near sample JV 2 (Fig. 2, B1). The nodules consist mainly of cordierite containing numerous inclusions of quartz and biotite. Grunerite, biotite, almandine, andalusite, quartz and magnetite occur between the lighter coloured conical structures which may represent relic flute moulds similar to those sometimes found in turbidites.

F. Hornblende-biotite tonalite gneiss (from locality JV 18, Fig. 2, B3) containing a partially metasomatized mafic inclusion. Nearer the greenstone contacts the gneisses are generally more strongly foliated and the xenoliths are aligned parallel to the gneissocity.

PLATE 2

A

B



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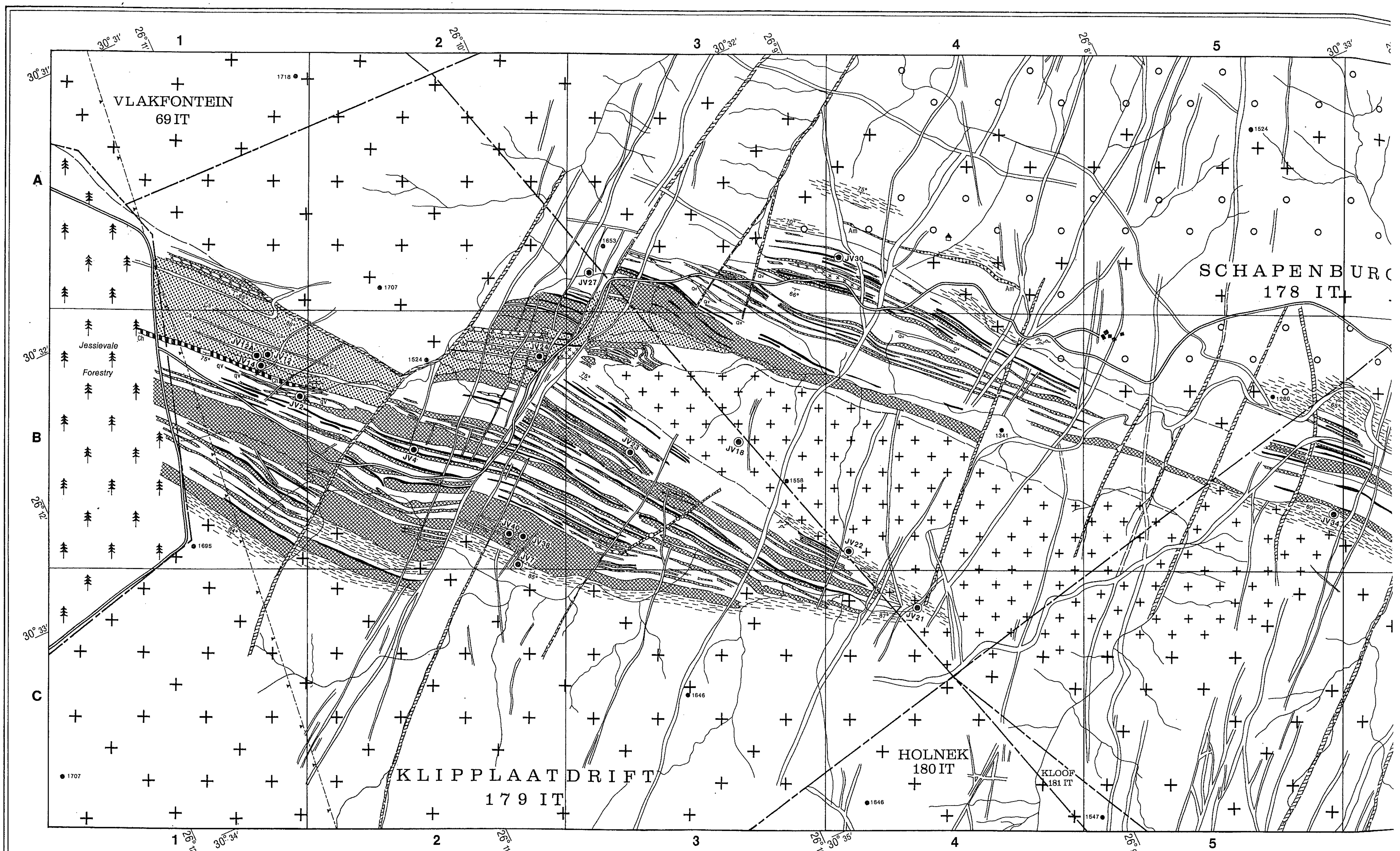


COUNTRY ROCKS – TJAKASTAO SUBGROUP, SWAZILAND SUPERGROUP

Metasediments, including metamorphosed greywackes (G) (biotite + quartz ± grunerite ± almandine ± cordierite ± staurolite ± andalusite ± pyrophyllite ± hornblende ± plagioclase ± magnetite), calc–silicate interlayers (Cs) (quartz ± diopside ± plagioclase ± tremolite ± actinolite ± grossularite ± almandine) and recrystallized chert (Ch)

Banded silicate facies iron-formation consisting mainly of hornblende (± actinolite) and quartz (recrystallized chert), ferruginous banded chert (gossanous in places)

Metabasaltic lavas and tuffs (undifferentiated high–Mg basaltic komatiites) now mainly altered to a variety of amphibole schists (hornblende ± tremolite ± actinolite) and chlorite or talc - chlorite schists

Serpentinized ultramafic rocks, interlayered peridotitic komatiite extrusives displaying spinifex textures in places, serpentinized coarse–grained harzburgites, tremolite ± talc ± carbonate ± chlorite schists

GRANITIC INTRUSIVES

Medium-to-fine-grained homogeneous, pinkish or pinkish–grey adamellite or granodiorite – foliated in places, particularly along contacts with greenstone schist belt remnants – foliation weakens progressively away from greenstone contacts

Small bodies of tonalite intruded into greenstone successions – generally parallel to the strike of the formations

Medium-to-fine-grained homogeneous tonalite containing numerous, randomly orientated, mafic schlieren. In places the tonalite may be foliated and gneissic, mesocratic or melanocratic, and with mafic schlieren aligned parallel to the gneissocity. Local lit-par-lit intrusive relationships with greenstone remnants evident in places

Foliated leuco–biotite trondhjemite / tonalite gneisses, streaky banded trondhjemitic gneisses and migmatites. Mafic xenoliths aligned parallel to foliation of gneisses. Granite–greenstone interaction results in development of migmatites near greenstone schist belt margins and in areas flanking greenstone xenoliths

MAFIC INTRUSIVES

Mafic dykes – mainly diabase but including porphyritic diabase, gabbro – diabase, and dykes with inclusions (undifferentiated)

Amphibolite dyke (Am) consisting mainly of hornblende together with pyroxene, plagioclase and quartz – represents a mafic dyke probably metamorphosed by the homogeneous pink adamellite / granodiorite

Faults, fractures, shear zones

Schistosity trends, foliation trends in granitic rocks

60° Dip and strike of bedding, schistosity, foliation

Jessievale plantations, pine forests

Rondavel

Farmhouse, sheds

Native kraals

Farm boundary

Tracks

River, stream, gulley

Quartz veins

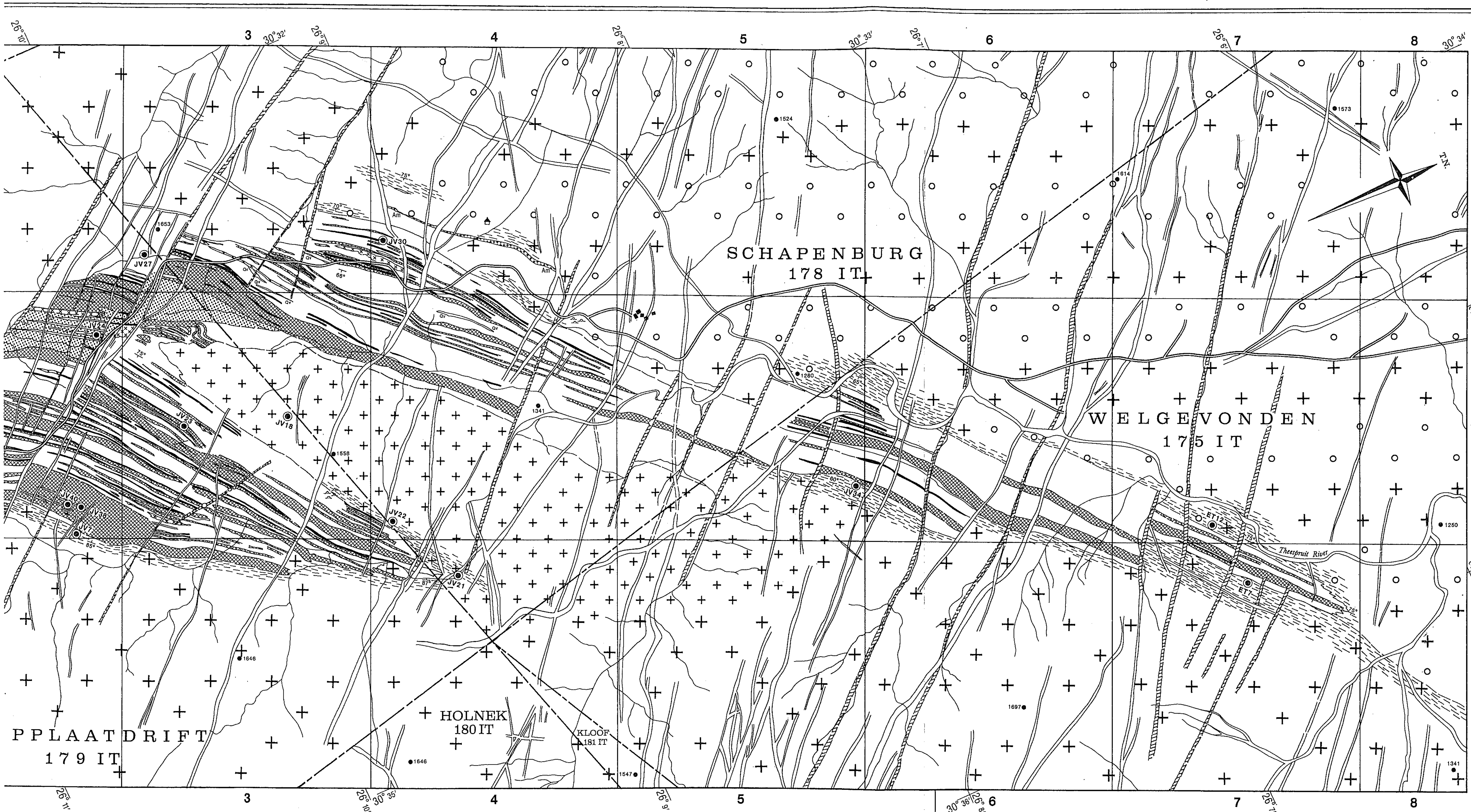
Spring

1573 Spot heights in metres

JV7 Sample chemically anal

Escom power line

Drawn by W. Job. 1981



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1573 Spot heights in metres

JV7 Sample chemically analysed

Escom power line

Drawn by W. Job, 1981

GEOLOGICAL MAP OF THE SCHAPENBURG GREENSTONE REMNANT AND SURROUNDING GRANITIC TERRANE, BARBERTON MOUNTAIN LAND

Geologically Surveyed by C. R. Anhaeusser (1976)

Scale in metres

1000 800 600 400 200 0 200 400 600 800 1000 1200 1400 1600 1800 2000