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THE GEOLOGY OF THE KALKKLOOF CHRYSOTILE ASBESTOS DEPOSIT AND SURROUNDING AREA, BARBERTON MOUNTAIN LAND

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ABSTRACT

Chrysotile asbestos deposits in the Barberton Mountain Land are mainly confined to layered ultramafic complexes. Most, but not all, of these ultramafic complexes appear to be penecontemporaneously associated with basaltic and peridotitic komatiite successions found in the lower division (Tjakastad Subgroup) of the Onverwacht volcanic sequence. The Kalkkloof Complex is of this type and occurs in a greenstone remnant that is separated from the Barberton greenstone belt by a trondhjemitic gneiss pluton which was intruded into the region approximately 3200 Ma ago.

The Kalkkloof layered body consists of a number of alternating serpentinized dunite and orthopyroxenite units together with interlayers of talcose schists. The complex has undergone considerable faulting and shearing and the original cumulate assemblages have been extensively altered by CO_2, Mg, and SiO_2 metasomatism. The chrysotile asbestos occurs mainly as cross fibre and is preferentially developed near and parallel to contacts between the soft, green, serpentinized dunite and the hard, massive, grey-green, serpentinized orthopyroxenite.

The main controls for fibre formation are :

(i) the presence of suitable high-Mg serpentinized dunite host rocks,

(ii) the differential structural competence between the dunites and the orthopyroxenites,

(iii) several episodes of faulting and fracturing of the Kalkkloof layered body and,

(iv) the availability of suitable serpentinous solutions to assist in fibre development. These solutions were probably first generated at the time of emplacement of the trondhjemitic gneiss pluton and again, later, following Proterozoic dyke and sill intrusion.

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CONTENTS

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THE GEOLOGY OF THE KALKKLOOF CHRYSOTILE ASBESTOS DEPOSIT AND SURROUNDING AREA, BARBERTON MOUNTAIN LAND

I. INTRODUCTION

The Kalkkloof chrysotile asbestos deposits occur in an Archaean greenstone enclave situated approximately 15 km west of the Barberton greenstone belt and 10 km north of Badplaas in the eastern Transvaal (Figure 1). The greenstone remnant, known as the Kalkkloof schist belt, is separated from the Barberton belt by intrusive trondhjemitic gneisses of the Nelshoogte pluton which is considered to be approximately 3200 Ma old (Barton et al., 1982; Oosthuyzen, 1970).

Proterozoic sedimentary rocks of the Transvaal Supergroup cover most of the Kalkkloof schist belt, which is only exposed where rivers associated with the upper drainage system of the Komati River have cut back through the cover sequences that form part of the Transvaal Drakensberg Escarpment.

The Kalkkloof deposit is one of a number of chrysotile asbestos occurrences, associated with layered ultramafic complexes, that have been mined in the Barberton Mountain Land. With the exception of the Havelock, Msauli, and Rosentuin ore bodies, these layered complexes appear to be related to extrusive sequences of basaltic and peridotitic komatiites that make up a large part of the lower ultramafic division of the Onverwacht Group (Tjakastad Subgroup) which, in turn, forms part of the Swaziland Supergroup.

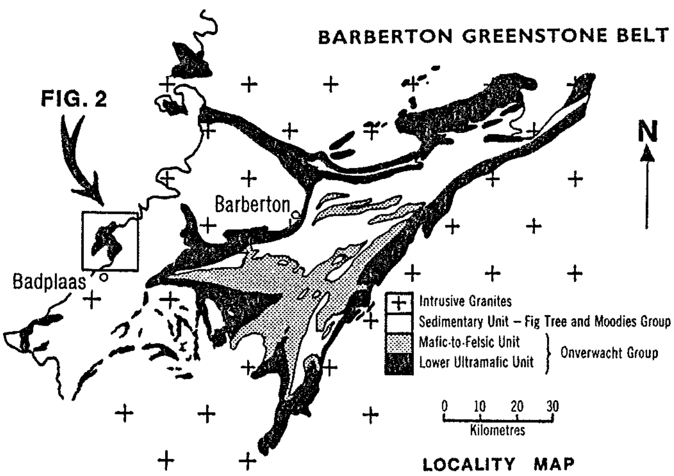

Figure 1 : General geological map of the Barberton Mountain Land showing the locality of the Kalkkloof schist belt and associated layered ultramafic complex.

According to Groeneveld et al. (1977) production at Kalkkloof began in 1928 when 17 tons of chrysotile fibre were first mined by Kloof Asbestos Limited. During 1929 and 1930 African Asbestos Trust Ltd., mined 385 tons of fibre and later, between 1941 and 1966, the Kalkkloof Asbestos Mine produced continuously and declared 39 097 tons of fibre. In addition, 439 tons of fibre were obtained from the reworking of tailings dumps during 1950 by the Western Asbestos Co. (Pty.) Limited. Reworking of the tailings dumps was again undertaken in 1967 after the mine had ceased underground production, and by the end of 1969 an additional 3 711 tons were recorded. After being temporarily closed the mine continued production between March 1972 and June 1977, when another 1 564 tons were extracted.

The African Asbestos Cement Corporation Ltd., operated the mine from 1946 to 1960 when the Johannesburg Consolidated Investment Company Limited acquired this company. Since 1967 the mine has been reinvestigated on a number of occasions but no further underground production has been recorded. To date, the Kalkkloof asbestos deposit has yielded a total of 45 214 tons of chrysotile fibre and, during the productive life of the mine, Canadian Box Standard Grades 5, 4, 3, 7 and 6 were obtained from the mill (the latter listed in order of abundance).

II. GENERAL GEOLOGY OF THE KALKKLOOF AREA

A. Introduction

Asbestos workings in the Kalkkloof valley were first described by Hall (1930) who noted that the fibre was associated with alternating light green, soft serpentinites (containing the chrysotile asbestos seams) and dark green, hard, talcose serpentinites. He compared the light green serpentinites with the olivine-bearing units in the Amianthus and Munnik-Myburgh mines near Kaapsehoop, whereas the darker serpentinites had similarities with the orthopyroxene-bearing units in the same area. Visser et al. (1956) provided a brief account of the Kalkkloof schist belt and correlated the geology of the area with the so-called "Jamestown Igneous Complex" which is now defunct according to more recent investigations in the Barberton region (Anhaeusser et al., 1966; Viljoen and Viljoen, 1969c). Instead, these predominantly mafic and ultramafic successions are regarded as part of the lower division of the Onverwacht Group.

During the period of production several geological maps of the mine area were prepared which remain unpublished and in company files. The accompanying geological map of the Kalkkloof ultramafic body (Figure 2*) largely incorporates these earlier findings and provides additional details of the area surrounding the mine.

The area depicted in Figure 2 comprises four separate geologic entities. From east to west these include :

(i) the Nelshoogte trondhjemite gneiss pluton,

(ii) the Kalkkloof schist belt,

(iii) the Proterozoic cover rocks of the Transvaal Supergroup, and

(iv) the Kalkkloof layered ultramafic complex.

B. Transvaal Cover Sequence

1. *Stratigraphy*

Rocks of the Transvaal Supergroup comprise the youngest stratigraphic units in the Kalkkloof Mine area and are responsible for partially covering the asbestos-bearing Kalkkloof ultramafic complex south of the main workings. The cover sequence in the map area consists of : (i) a basal quartzite (Black Reef Quartzite), (ii) a stromatolite-bearing dolomite-chert-shale assemblage which is followed upwards by a thick chert autobreccia, together with conglomerate and gritty quartzite units near the top (Malmani Dolomite), and (iii) a thin layer of purple shales capping the succession and lying with a slight disconformity above the lower units. These purple shales form part of the base of the Timeball Hill Formation of the Pretoria Group (Fountains Member, Button, 1973).

The total thickness of the cover sequence varies from 100 m in the south and east to 200 m in the northwest. The Black Reef Quartzite and the Malmani Dolomite formations have a consistent combined thickness of approximately 80 m and the Pretoria shales thicken rapidly to the northwest and have a regular, gentle, dip of 10 degrees in that direction. Dolerite/diabase sills, with thicknesses of 2-10 m, are present within the cover sequence.

The unconformity between the greenstones and the overlying Transvaal sequence is generally well-exposed since the basal quartzite is well-jointed and tends to break off to form small cliffs. To the west and southwest of the Kalkkloof valley the ultramafic complex appears to have formed a palaeotopographical high, since the serpentinitic rocks are covered by successively higher units of the Transvaal sequence, being ultimately covered in places by the Pretoria shales. Field evidence suggests that the serpentinite hills must have had a relief of as much as 100 m at the time of deposition of the Transvaal rocks. The sediments lapping onto the central portion of the Kalkkloof layered complex display greenstone detritus derived from the erosion of the serpentinite body. On the southwest and southern flanks of the complex the cover sequence is highly disturbed structurally. Complex step-faulting occurs between basement and cover rocks in this area indicating a movement of serpentinites penecontemporaneous with Transvaal deposition (c. 2200 Ma ago). The faulted zone lies adjacent to the areas of major economic chrysotile fibre growth in the Eastern, Central and Southern sections of the mine (Figures 2 and 3). Some of the faulting extends into the serpentinite body where it appears to lie parallel to the layering of the altered dunites and orthopyroxenites.

C. Dykes and Sills

A variety of dolerite/diabase dykes and sills of different ages are intruded into various geological units in the map area. These include :

(i) post tonalite-trondhjemite but pre-Transvaal diabase dykes and sills, and

(ii) post Transvaal dolerite dykes and sills.

1. *Pre-Transvaal Diabase Dykes*

Diabase dykes, many of which form resistant outcropping ridges, occur throughout the Nelshoogte pluton where they can often be traced continuously over many kilometres. They are usually medium-to-fine-grained and show mainly the effects of deuteric alteration, being chloritized and saussuritized to varying degrees. These dykes generally have a preferred NW orientation but several dykes striking NE and N-S have been recorded. None of these dykes cut the cover sequence in the map area.

* Figure 2 - Folded map following page 10.

2. *Pre-Transvaal Diabase Sills*

Two sills of altered diabase occur in the trondhjemite gneisses east of Alexandria Buttress (Figure 2) and a third was noted in the amphibolite schists in the Gugwane valley area.

3. *Post-Transvaal Dolerite Dykes*

Visser et al. (1956) recorded a large olivine diabase dyke intruded along a N-S-trending fault running down the Kalkkloof valley and through the mine area. Investigations undertaken as part of this study confirmed the presence of a dyke cutting the Transvaal sequence in the northern part of the map area (Figure 2) as well as on the southern part of the farm Kalkkloof 706 JT, where it is offset by faulting. The dyke could not be located in the layered ultramafic complex except in the south. Furthermore, detailed mapping could not confirm the presence of a major fault extending down the Kalkkloof valley. Petrologically, the dyke reported above consists of plagioclase (labradorite), ophitic-textured pigeonite, and ilmenite. No olivine was evident.

4. *Post-Transvaal Dolerite Sills*

Dolerite sills intrude the Transvaal succession at several stratigraphic levels and vary between 2-10 m in thickness. Chill margins are well-developed at contacts with the cover sequence and in thin section the dolerite displays long-bladed diopsidic augite, partly altered to chlorite, and a groundmass of labradorite and augite.

The sills are of interest economically in places along the escarpment where they intrude cherty dolomite. Contact reactions have resulted in the development of serpentine in the dolomite and in places good quality chrysotile asbestos fibre deposits have formed (Anhaeusser, 1976; van Biljon, 1964). The Waterfall Section of the Kalkkloof Mine, just west of the area shown in Figure 2, is a deposit of this type.

The intrusive sills commonly produce a metamorphosed assemblage extending for a metre or more above the upper chilled contacts. The controls on the mineralization associated with these sills were outlined by Button (1973), and involve :

(i) a source of both Mg and Si (the former is supplied by the dolomite, the latter by the interbedded chert),

(ii) a source of H_2O (supplied by volatiles streaming off the cooling sill), and

(iii) a source of heat to drive the thermal reaction (supplied by the sill itself).

The precise ages of most of the dyke and sill intrusives remain to be determined. Many of them are, however, believed to be associated with the igneous activity that led, ultimately, to the emplacement of the Bushveld Igneous Complex west of the escarpment region. Some dykes are older and probably acted as feeders to volcanic units associated with the Godwan and Wolkberg sequences developed in the Badplaas-Kaapsehoop area. The youngest intrusive events were probably associated with late Karoo igneous activity.

D. The Kalkkloof Schist Belt

Rocks forming part of the Archaean Kalkkloof schist belt remnant are best developed in two river valleys (Gugwane and Ntshengane) situated northeast of the Kalkkloof layered complex (Figure 2). The predominant rock types include a wide variety of mafic and ultramafic schists (hornblende-actinolite-chlorite-talc-tremolite schists) the latter representing the structurally altered and metamorphosed equivalents of basaltic and peridotitic volcanic rocks. On the northern flank of the Gugwane valley pillow structures are preserved that indicate a younging direction to the south in this area. Interlayered with the mafic and ultramafic rocks are several siliceous schist horizons (quartz-sericite-fuchsite schists) resembling those reported in the Theespruit Formation in the Jamestown schist belt north of Barberton (Anhaeusser, 1972) and in the Komati river valley (Viljoen and Viljoen, 1969b).

In the Gugwane valley the formations strike NE to ENE and dip steeply to the southeast. Near the contact with the Nelshoogte pluton the schists are sub-vertical and metamorphosed to amphibolite facies. Within 100 m of the contact the metamorphic grade decreases to greenschist facies assemblages, with hornblende being replaced mainly by actinolite or chlorite in the basaltic rocks. Ultramafic units occur interlayered with the basalts and are represented by serpentinites, bronze and silver talc or talc-carbonate schists, and tremolite ± talc ± carbonate ± chlorite schists.

Geochemically, the mafic and ultramafic successions in the Kalkkloof schist belt have affinities with the peridotitic and basaltic komatiites and tholeiitic basalt sequences reported from the basal portion of the Onverwacht Group type section in the nearby Barberton greenstone belt. Table 1, columns 1-9, provides analyses of a variety of basalts and a peridotite unit found in the Kalkkloof schist belt and lists, for comparison, average analyses of similar rocks from the Barberton greenstone belt. The rocks analysed from the Kalkkloof schist belt have been structurally and thermally altered relative to the type section material and this aspect should be borne in mind when comparing the data from the two areas. Despite the differences, it is evident that the Kalkkloof greenstone remnant is comprised of assemblages that correlate with the formations of the lower Onverwacht Group. Peridotites and their alteration products, although present, are, nevertheless, subordinate to the basaltic rocks. It is of interest to note that many of the layered ultramafic complexes associated with the lowermost stratigraphy of greenstone belts (like the Kalkkloof body), are often situated in, or adjacent to, peridotite-poor extrusive successions. This is particularly evident with regard to some of the Kaapmuiden-Malelane complexes (Viljoen and Viljoen, 1969e) as well as the Stolzburg Complex in the Nelshoogte schist belt (Anhaeusser, 1976) and the Muldersdrif Complex north of Krugersdorp (Anhaeusser, 1978). From this relationship Anhaeusser (1978) inferred that where peridotite flows are either absent, or only sparsely developed, the ultramafic magma (that, given other conditions, would have erupted as flows) has accumulated in massive sill-like chambers and has undergone olivine, orthopyroxene and, in some cases, clinopyroxene fractionation, leading eventually to the development of a layered complex consisting of dunites, orthopyroxenites, websterites and gabbroic igneous rocks.

In the Kalkkloof and Ntshengane valleys the Kalkkloof layered body is in contact with quartz-rich schists and cherts on its northeastern and southeastern flanks (Figure 2). In the northeast, black and white banded, recrystallized, cherts, quartz-sericite-fuchsite-chlorite-tremolite schists, and some meta-greywackes, are truncated by a NW-trending fault near the junction of the Kalkkloof and Ntshengane rivers. In the southeast, Transvaal cover rocks and scree obscures much of the area but where the contact is exposed the serpentinites are juxtaposed to a 100 m-wide unit of black and white banded meta-cherts and reddish-grey meta-greywackes. These rocks, in turn, are followed eastwards by talc-chlorite-tremolite schists. In all cases the schists flanking the Kalkkloof ultramafic body appear to be conformable with the layering of the complex.

In the valley west of the Kalkkloof layered body exposure is poor and no contacts can be seen between the serpentinites and the few outcrops of meta-greywacke schists present in the area (i.e. quartz-chlorite-mica schists with cross-bedded structures).

The absence of continuous exposure and the presence of the younger cover sequence renders structural and stratigraphic correlation between the Gugwane and Kalkkloof valley greenstone exposures rather tenuous. However, available structural evidence suggests that the Kalkkloof schist belt represents a large-scale, gently SW-plunging, anticlinal structure with the fold axial trace extending from the farm Grootkop 617 JT in a NNE-SSW direction across Kalkkloof 706 JT. This is assumed principally because all the successions in the Kalkkloof valley, including the layered complex, dip and young to the west, whereas in the Gugwane valley all the units dip steeply to the southeast and evidence from pillow lavas indicates younging in the same direction.

E. The Nelshoogte Pluton

Intrusive into the Kalkkloof schist belt and separating it from the Nelshoogte schist belt in the Barberton greenstone belt is a leuco-biotite trondhjemite gneiss pluton approximately 18 km in diameter. The central portion of the pluton is relatively homogeneous, yet foliated, whereas in the southeastern portion of the map area (Figure 2) the trondhjemite gneiss near the contact with the Kalkkloof schist belt is highly sheared and jointed and contains large (500 x 100 m) as well as small (50 x 10 m) xenolithic lenses of amphibolite, serpentinite and quartz-chlorite schist. The small lenses or schlieren are generally aligned parallel to the foliation which intensifies in the gneisses near the contact with the schists in the Gugwane valley.

Also in the Kafferskraal (618 JT) and Alexandria (707 JT) areas (Figure 2) there are extensive faults or shear zones in the gneisses now occupied by prominently outcropping, white vein quartz. Some of the quartz-filled veins are up to 10 m wide and can be traced for over 3 km. One quartz-filled fracture extends into the Gugwane schists causing them to be displaced sinistrally for approximately 300 m.

The trondhjemite gneiss varies from fine-to-coarse-grained and displays migmatitic banding in places. The gneiss consists predominantly of albite, quartz, and biotite (some altered to chlorite) with lesser amounts of orthoclase, microcline, epidote, muscovite, sphene, and epidote. Two chemical analyses of the Nelshoogte trondhjemite gneiss (one from the map area, Figure 2 , and the other from the central portion of the pluton) are listed in Table 1, columns 10 and 11. Both analyses show the distinctive trondhjemite characteristics defined by Barker (1979) and which include, among others, $SiO_2 > 68$ per cent, Na_2O 4,0-5,5 per cent and $K_2O < 2,5$ per cent.

Geochronological studies have yielded an U-Pb zircon age of 3220 ± 80 Ma (Oosthuyzen, 1970) and a Rb-Sr whole rock age of 3180 ± 75 Ma with a low initial $^{87}Sr/^{86}Sr$ ratio of 0,7010 ± 0,0011 (Barton et al. 1982).

III. THE KALKKLOOF LAYERED ULTRAMAFIC COMPLEX

A. General Geology

The Kalkkloof ultramafic body, which was buried beneath the Transvaal cover sequence, has been partly exposed in the deeply dissected Kalkkloof and Ntshengane valleys. The layered complex is best displayed on the farm Kalkkloof 706 JT where continuous outcrops occur over a distance of approximately 5 km in a N-S direction and where the maximum width of exposure is about 1,5 km. The body outcrops again further north of the area shown on Figure 2, on the farm Racesbaan 616 JT, and it extends southwards beneath cover rocks for an unknown distance. The total length of the complex is probably 10 km or more.

As mentioned earlier, the layered body abuts against various siliceous schists and chert on its eastern flank and faulting obscures the direct relationship between the complex and the neighbouring greenstone assemblages of the Kalkkloof schist belt. As shown schematically in Figure 3 the layered body consists of at least two major cycles of alternating light- to dark-green soft serpentinites and dark-green-to-grey hard serpentinites. These serpentinite varieties represent highly altered dunites and orthopyroxenites respectively, and the cycles dip 50-60° to the west and appear to young in this direction as well.

In detail, the two major cycles can be shown to consist of a complexity of thin, and often discontinuous, layers of one serpentinite type within the other. Thick, discontinuous, bands of soft-weathering talc schists are also present along the contacts between the various serpentinites and smaller talcose lenses occur within the massive serpentinite units. Detailed surface mapping of these lenses is rendered difficult due to the massive blocky nature of the exposures and the abundance of ultramafic scree on the hill slopes in the area.

TABLE 1

COMPARISON OF THE CHEMISTRY OF VARIOUS ROCK TYPES FOUND IN THE KALKKLOOF SCHIST BELT AND KALKKLOOF ULTRAMAFIC COMPLEX WITH THAT OF SIMILAR MATERIAL FROM THE BARBERTON GREENSTONE BELT

	Peridotitic and Basaltic Komatiites and Tholeiitic Basalts									Trondhjemitic Gneisses		Altered Ultramafic Rocks			Intrusive Porphyries	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	RM42$^{\phi}$	R13	RM40$^{\phi}$	Ave	RM43$^{\phi}$	Ave	Ave	RM46$^{\phi}$	Ave	RM8$^{\phi\dagger}$	KL7	C1†	Ave	RM74†	RM75†	VP5
SiO_2	40,44	39,41	43,36	47,37	51,10	52,22	52,73	50,41	52,13	72,70	70,57	51,40	53,94	26,60	67,59	68,84
TiO_2	0,19	0,21	0,36	0,46	0,45	0,56	0,85	1,28	1,09	0,06	0,29	0,10	0,08	0,02	0,40	0,30
Al_2O_3	3,75	2,67	9,42	6,79	9,49	5,42	9,83	13,81	13,33	15,41	15,01	1,10	1,50	0,18	15,69	14,60
Fe_2O_3	5,61	4,97	2,67	1,18	2,60	0,98	1,23	4,47	2,24	0,35	2,39*	6,60*	0,94	4,67*	2,25*	0,26
FeO	5,85	5,83	9,17	8,08	7,75	8,88	9,70	8,65	9,94	0,35			6,19			1,51
MnO	-	0,16	-	0,19	-	0,22	0,22	-	0,21	-	0,03	-	0,18	-	-	0,05
MgO	30,66	30,97	20,47	20,39	13,99	15,25	10,10	6,77	6,35	0,17	0,87	30,60	30,65	30,63	2,22	1,45
CaO	0,31	2,31	6,76	8,31	9,13	12,83	9,99	8,21	8,98	2,24	3,02	1,40	1,95	10,68	0,74	2,80
Na_2O	0,06	0,02	0,31	0,39	1,27	1,21	2,65	1,94	2,97	5,69	5,54	2,60	0,05	0,08	5,65	5,12
K_2O	0,01	0,02	0,02	0,06	0,22	0,09	0,46	0,81	0,26	2,17	1,36	0,40	0,09	0,04	2,65	1,61
P_2O_5	-	-	-	0,05	-	0,05	0,06	-	0,07	-	0,13	-	0,03	-	-	0,11
H_2O	10,37	11,78	4,99	5,51	-	2,14	-	-	2,08	-	-	-	4,61	10,50	-	1,13
CO_2	0,08	n.d.	0,14	-	-	0,17	-	-	0,07	-	-	-	0,13	13,60	-	2,60
L.O.I.	-	-	-	-	2,00	-	-	1,72	-	0,89	0,82	6,75	-	-	1,76	-
TOTAL	97,53	98,35	97,67		98,00			98,07		99,83	100,03	100,70		97,03	98,95	100,38

Analysts : ϕ R.P. Menell, Cambridge University
$\dagger$ J.R. Delve, Cambridge University
* Total Fe as Fe_2O_3

Columns :
1. Massive talcose serpentinite (altered peridotitic komatiite), Gugwane valley, Grootkop 617 JT.
2. Extensively, but not completely, serpentinized peridotite (Viljoen and Viljoen, 1969a).
3. Massive tremolite-chlorite rock, Gugwane valley (altered Geluk-type basaltic komatiite).
4. Average Geluk-type basaltic komatiite (Viljoen and Viljoen, 1969b).
5. Amphibolite schist (actinolite-quartz-albite), Gugwane valley (altered basaltic komatiite).
6. Average Badplaas-type basaltic komatiite (Viljoen and Viljoen, 1969b).
7. Average Barberton-type basaltic komatiite (Viljoen and Viljoen, 1969b).
8. Amphibolite schist (actinolite-quartz-albite-epidote), Gugwane valley (altered tholeiitic basalt).
9. Average metatholeiite, Lower Ultramafic Unit, Onverwacht Group (Viljoen and Viljoen, 1969b).
10. Trondhjemitic gneiss, western margin of the Nelshoogte pluton, Kafferskraal 618 JT.
11. Leuco-biotite trondhjemite gneiss, central part of Nelshoogte pluton, Vygeboom 619 JT (Anhaeusser, unpublished data).
12. Massive talcose serpentinite (altered orthopyroxenite), Kalkkloof layered ultramafic complex, Kalkkloof 706 JT.
13. Orthopyroxenite (enstatite-bronzitite). Average of 20 analyses, Stolzburg layered ultramafic complex (Anhaeusser, 1976).
14. Grey, massive, carbonated serpentinite (steatized and metasomatized dunite), Kalkkloof 706 JT.
15. Quartz-feldspar porphyry lens in serpentinites, Kalkkloof 706 JT.
16. Quartz-feldspar porphyry intrusive, Komati Formation type locality (Viljoen and Viljoen, 1969b).

Two small quartz-feldspar porphyry lenses occur between the Central and East sections of the mine (Figure 2). One of these porphyry bodies is conformable with the layering but poor exposure does not allow the relationship of the second body to be ascertained. Quartz-feldspar porphyry bodies have been described in the Handsup-Mundt's Concession layered ultramafic complex in the Jamestown schist belt north of Barberton (Anhaeusser, 1972). In this region, it appears that the porphyries were intruded into the ultramafic successions thereby being responsible for the development of talc deposits in areas flanking the intrusives. Quartz-feldspar porphyries also occur in the Komati Formation type locality (Viljoen and Viljoen, 1969b) and in the Msauli asbestos mine area (Voigt et al., 1982). In some cases the porphyry bodies appear to be younger intrusives (as at Msauli Mine), but elsewhere the possibility remains that they may be genetically linked to the ultramafic sequences, being contemporaneous felsic fractionates similar to the "oceanic plagiogranites" reported from ophiolites (Coleman and Peterman, 1975).

Three prominent faults cut across the Kalkkloof ultramafic body causing disruption of the layered units (Figure 2). From north to south these include : (i) a major NW trending fault separating the North Section from the remainder of the complex and having a displacement of approximately 1 500 m to the southeast, (ii) a WNW-trending fault in the central part of the complex displacing the southern block a further 200 m to the southeast, and (iii) a NW-trending fault near the South Section which again displaces the formations to the southeast another 200 m. All three faults display sinistral displacement and do not appear to have provided any significant mining problems.

The southeast flank of the layered body, together with an underlying conformable, meta-chert/shale unit, is reverse faulted against Transvaal cover rocks (Figure 3) such that the topmost serpentinite exposed lies 60 m above the undisturbed basal Black Reef Quartzite. In addition, the upfaulted serpentinites are capped by a 5 m layer of highly sheared and disturbed dolomites, quartzites, and shales, suggesting that fault disruption may have taken place during, or just after, the deposition of the cover sequence. Faulting, or at least shear

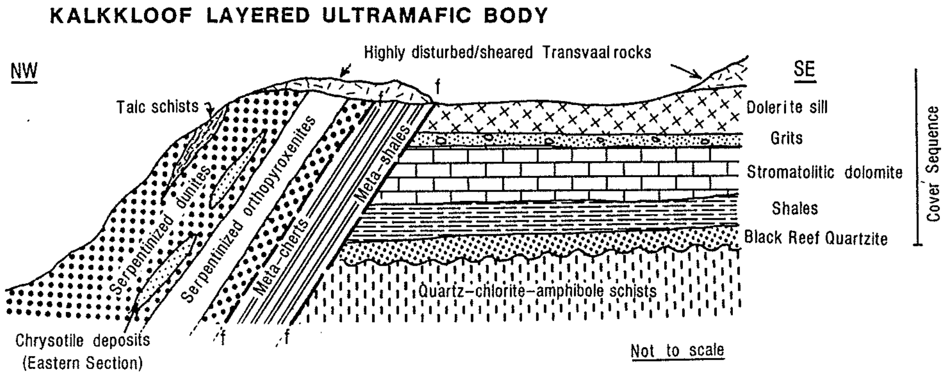

Figure 3 : *Diagrammatic NW-SE section across the Kalkkloof layered ultramafic body showing the reverse faulted nature of the contact between the rocks of the Swaziland succession and the younger, subhorizontal, Transvaal cover sequence, on the southeast flank of the Kalkkloof valley near the East Section of the asbestos mine.*

movement conformable with the layering of the Kalkkloof Complex, appears to be present in the mine area. These displacements probably took place along contacts and are largely responsible for producing the structural conditions favourable for the subsequent development of asbestos fibre zones.

B. Petrology and Geochemistry

The Kalkkloof body comprises a wide range of ultramafic rock types represented principally by serpentinized dunites and orthopyroxenites but also probably including rocks that were formerly harzburgites or wehrlites. Apart from extensive alteration to serpentinites these rocks have also been sheared in places and have been subjected to CO_2, SiO_2, and Mg metasomatism. This has resulted in the development of a wide variety of talc ± tremolite schists and other steatized, uralitized and carbonatized ultramafic assemblages. Among the unusual products found in the mine area are showings of stichtite, a lilac-coloured mineral (Mg_6 Cr_2 $(CO_3)(OH)_{16}$. 4 H_2O) which is dimorphous with pinkish coloured barbertonite. These minerals have been reported in a number of other asbestos deposits in the Barberton region, but principally at the New Amianthus, Munnik-Myburgh and Sterkspruit mines (Hall, 1930; Frondel, 1941). Also developed at Kalkkloof are occurrences of magnesite, and calcite/serpentinite rocks showing no relic texture (an analysis of the latter is listed in Table 1, column 14).

The dunites comprise olivine cumulates with the olivine crystals totally pseudomorphed by antigorite/ lizardite. Fibrous stichtite occurs in the interstices between the altered olivine grains that average approximately 3 mm in diameter. Magnetite and altered chromite grains are also common. Relic olivine was not recorded in this study but was noted by Visser et al. (1956) in fresh samples from deep within the mine. Chrysotile, magnesite, and magnetite slip-fibre growth is common wherever the soft serpentinites are sheared, and intergrowths of magnetite and fibrous magnesite have been observed.

Alternating with the soft dunitic serpentinites are resistant ridges of reddish-brown-weathering orthopyroxenite, the latter being dark-grey-to-green on fresh surfaces. The orthopyroxenites consist mainly of antigorite and talc, together with many relic orthopyroxene crystals (enstatite-bronzite), bastite, tremolite and ilmenite. The relic orthopyroxenites also display cumulate textures and crystals measuring up to 15 mm in length were noted.

Chemically, the Kalkkloof orthopyroxenites are similar to those of the Stolzburg layered body in the Nelshoogte schist belt approximately 18 km to the east. Table 1 (columns 12 and 13) shows the striking similarity of the rocks from the two areas. Only Na_2O is anomalously distinctive in the single sample analysed from the Kalkkloof area. Serpentinized orthopyroxenites also differ chemically from the serpentinized dunites in the Barberton layered complexes by having higher SiO_2, and lower total iron, MgO and H_2O contents (Anhaeusser, 1976). The higher silica probably accounts for the fact that the orthopyroxenite units are physically more resistant than the interlayered dunites. In addition, the orthopyroxenite units are hardly sheared at all, and exhibit no stichtite, chrysotile, magnesite, or magnetite fibre growth, except rarely near contacts with the softer serpentinites.

Schists, consisting of pure talc, or talc-tremolite-chlorite schists, occur as bands up to 400 m long and 100 m wide in places at the contact between the dunites and orthopyroxenites. Smaller lenses of talcose schist occur interlayered within both these rock units. The schists are invariably aligned parallel to the layering within the complex and are blue- to silver-grey or bronze coloured (the latter indicating carbonatization).

The quartz-feldspar porphyry bodies southeast of the Central Section workings (Figure 2) consist mainly of large (up to 5 mm) euhedral to subhedral crystals of albite and quartz. The albite is partially sericitized and saussuritized and the matrix comprises quartz, biotite, albite, zoisite and, more rarely, pyroxene replaced by tremolite. Table 1, columns 15 and 16, compares analyses of porphyry bodies from the Kalkkloof area and the Komati Formation type locality. Like the nearby Nelshoogte pluton, the porphyry bodies are Na-rich and may be genetically linked to this trondhjemitic intrusive body. However, it is equally possible that they may represent an earlier intrusive stage like that suggested for some of the felsic porphyry bodies intruded into the Jamestown schist belt (Anhaeusser, 1972).

IV. THE KALKKLOOF ASBESTOS DEPOSIT

Hall (1930) and van Biljon (1964) provided geological descriptions of the mine workings based on evidence then available. Access to the underground workings was not possible during the present study but information made available from a report of the Johannesburg Consolidated Investment Co. Ltd., (Mulder, 1960), and the Geological Survey of South Africa open file documents (Groeneveld, 1977), provide the most recent account of the mine which ceased underground activities in 1967.

The mine comprises one major ore deposit (the Central or Main Section) and five other deposits. In order of importance these are :

(i) the South Section, 248 m above and 1 240 m south of the Central Section,

(ii) the Slip Fibre Section, 2 015 m southwest of the Central Section,

(iii) the North Section, 2 170 m north of the main workings and,

(iv) the East Section, 682 m southeast of the main workings.

In addition, there is the Waterfall Section, approximately 3 km west of the Central Section, but which occurs not in the Kalkkloof layered complex but in cherty dolomites of the Transvaal cover sequence. All the deposits except the last mentioned occurrence are located on Figure 2.

The chrysotile asbestos fibre generally occurs in a number of parallel, tabular, bodies along the contact zones of alternating serpentinized pyroxenite and dunite and is mainly confined to the latter host rock. The average dip of the interbedded lodes is 65° west or west-northwest and their width varies from a few centimetres to 2,5 m. Chrysotile occurs in the lodes in a varying number of parallel seams (ribbon fibre seams like those displayed in the New Amianthus Mine, Laubscher, 1982), with occasional offshoots in either the hanging- or foot-walls. Seam widths may be from 1,5 mm up to a maximum of 6,35 cm and often spaced at regular intervals to form a true ribbon pattern. In ore of this type chrysotile forms between 25 and 60 percent of the rock. Ribbon fibre of the type described occurs most often adjoining the contact with the orthopyroxenites, with wider seams developed at regular intervals further away from the contact zones.

As described by Groeneveld (1977) the Kalkkloof fibre possesses good tensile strength, is flexible, silky white when fluffed, has a low iron content, and the strands separate easily. Local undulations along both strike and dip do not appear to influence the quality or the quantity of the mineralization but towards the lateral limits of the lodes disturbance generally becomes more pronounced and the mineralization is intermittent and finally absent. Asbestos fibre decreases, or is absent, in areas where shearing is either strong or weakly developed. The optimum conditions for fibre development appear to be in areas that have been stressed but which have not been unduly disturbed during or after fibre growth.

The Central Section yielded the most fibre during the life of the mine. In this area upwards of ten parallel lodes strike in a NNE direction (Figure 4). In order of importance the main supplies of ore have come from the Main lode, X-lode, New lode, West lode, and Mill Site lode. The other lodes have not, as yet, been of exploitable value but, with changing economic circumstances, could prove viable in the future. The Main lode, which is over 1 000 m in length, has supplied the bulk of the fibre. It has proved to be more consistent, in terms of quality and quantity, than the other lodes which have only been mined intermittently in places where extremely rich patches of chrysotile have been encountered. Details of the lode widths, lengths, and values were provided by Groeneveld (1977) but, as this information applied to the early 1960's, its relevance today is debatable and has not been repeated here.

The South Section has three separate ore bodies, not connected with any of the lodes of the Central Section to the north. The West lode, which is over 300 m long, was the main fibre supplier, with the Quarry lode and the North lode providing ore intermittently.

The Slip Fibre Section consists of a large body of slip fibre chrysotile with cross fibre at the contacts between the serpentinized dunite and orthopyroxenite units. The slip fibre formed along shear planes in the serpentinites but is only of fair quality. The deposit was proved over a length of 108 x 55 m in the 1960's and could be quarried. Two lodes of cross fibre chrysotile are developed on either side of the slip fibre zone, the east lode being approximately 186 m long. The maximum length of the cross fibre is 13 mm in the east lode and 19 mm in the west lode.

The North Section again comprises several lodes, some containing patches of good quality, long fibre seams, the latter also developed at dunite/orthopyroxenite contacts. The underground workings, as with all the other deposits at the Kalkkloof Mine, are accessible by means of adits driven into the hillsides.

The East Section comprises a strongly folded lode along a strike length of about 220 m, and a width of 32 cm. Here too, the mineralization developed at a dunite/orthopyroxenite contact but, in places, the fibre is silicified. The mineralization elsewhere is very erratic with high grade, long fibre seams alternating with distorted, barren sections.

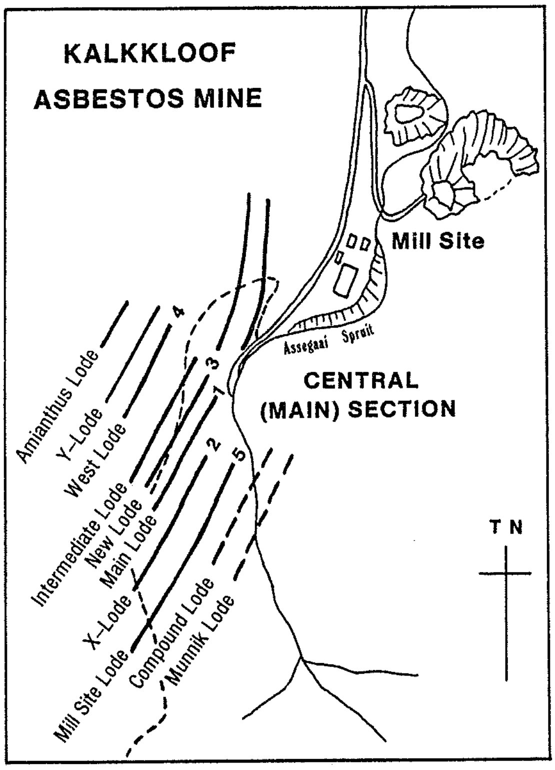

Figure 4 : *Schematic map of the Central or Main Section of the Kalkkloof asbestos mine showing the distribution of ten of the fibre-bearing lodes developed in the area. The Main Lode, which is over 1 000 m long, has supplied most ore, followed in order of importance by the X-lode, New lode, West lode, and the Mill Site lode.*

In summary, the bulk of the asbestos fibre at Kalkkloof occurs in serpentinized dunites at the contacts between this rock type and the more massive, structurally resistant, serpentinized orthopyroxenites. Precisely the same fibre control is evident at a number of asbestos mines in the Barberton area where layered ultramafic complexes comprising dunites, orthopyroxenites, harzburgites and, in some cases, websterites and gabbros, or gabbroic anorthosites, are developed. Principal examples of deposits very like Kalkkloof are the New Amianthus, Munnik Myburgh, and Star deposits in the Jamestown schist belt and the Sterkspruit, Stolzburg, and Doyershoek deposits in the Nelshoogte schist belt (Anhaeusser, 1976; Groeneveld, 1977; Hall, 1930; Laubscher, 1982; van Biljon, 1964; Viljoen and Viljoen, 1969d).

It appears that optimum fibre formation occurs in serpentinized dunites that, during deformation, suffered dilation and the production of micro fractures. These fractures seem to be best developed near contacts with more competent rock types, such as quartzites in parts of the New Amianthus deposit (Laubscher, 1982), and orthopyroxenites in most other cases (Anhaeusser, 1976). Migrating serpentinuous solutions subsequently made their way into the fractures and, in this tensional environment, crystallized ultimately as cross fibre chrysotile asbestos. The serpentinuous solutions, it is speculated, resulted from the dissolution of the parent dunite by migrating fluids set in motion by a local heat source. In the Kalkkloof area this may have taken place in stages, beginning with the emplacement of the Nelshoogte pluton and, again later, following the intrusion of the dykes and sills of varying age found in the vicinity of the mine.

V. SUMMARY AND CONCLUSIONS

The Kalkkloof schist belt is an Archaean greenstone enclave consisting of metavolcanic and metasedimentary rocks comparable to those found in the Tjakastad Subgroup which forms the basal mafic-ultramafic subdivision of the Onverwacht Group in the Barberton greenstone belt. The schist belt, which appears to form a large anticlinal structure with a gentle plunge to the southwest, is truncated in the northeast by the Nelshoogte trondhjemite gneiss pluton. This intrusive diapiric body is believed to have isolated and separated the Kalkkloof schist belt from the Nelshoogte region of the Barberton greenstone belt approximately 3 200 Ma ago.

The Archaean granite-greenstone terrane was later covered by Proterozoic Transvaal Supergroup rocks consisting essentially of quartzites, dolomites, cherts, shales, cherty autobreccia, conglomerates, and grits. Subsequent erosion in the Komati River drainage system resulted in the partial exposure of the Kalkkloof schist belt and the Kalkkloof layered ultramafic complex. This ultramafic body, which is the host to at least six chrysotile asbestos deposits, can be correlated with a number of asbestos-bearing layered bodies in the Barberton greenstone belt, particularly the Stolzburg Complex in the Nelshoogte schist belt and the Kaapsehoop Complex in the Jamestown schist belt (Anhaeusser, 1976).

The Kalkkloof layered body consists of alternating layers of serpentinized dunite and orthopyroxenite together with interlayers of pure and impure talc schists. The entire complex has been heavily tectonized and the original cumulate minerallogy (olivine, orthopyroxene, clinopyroxene) has undergone extensive alteration (serpentinization) including CO_2, Mg, and SiO_2 metasomatism.

The serpentinized dunites of the layered complex are the host to chrysotile asbestos fibre deposits which have been exploited between 1928 and 1977. At present the mine is closed. The chrysotile occurs mainly as cross fibre bands and the economically recoverable ore has always been exploited near and parallel to contacts with the harder, more massive, serpentinized orthopyroxenite layers (enstatite-bronzite cumulates). Slip fibre of fair quality was exploited from one section of the mine but constituted only a minor portion of the production.

The controls on the development of suitable chrysotile asbestos fibre in the area appear to be as follows:

(i) the availability of suitable high-Mg serpentinized dunite host rock,

(ii) the differential competence between the softer green serpentinized dunite and the more massive, harder, dark grey or blue-green serpentinized orthopyroxenite,

(iii) several episodes of deformation, beginning with folding and faulting during the Archaean and, again later, when at least the southern half of the Kalkkloof layered body underwent further deformation during and after deposition of the Transvaal cover sequence. In this area the Central, South and East sections of the Kalkkloof Mine have produced by far the greater tonnages of fibre, and

(iv) the availability of suitable serpentinous solutions to fill the fracture voids created during tensional deformation episodes. These solutions were probably initiated and allowed to circulate following the emplacement of the Nelshoogte pluton, and again later, following the emplacement of the Proterozoic dykes and sills in the area.

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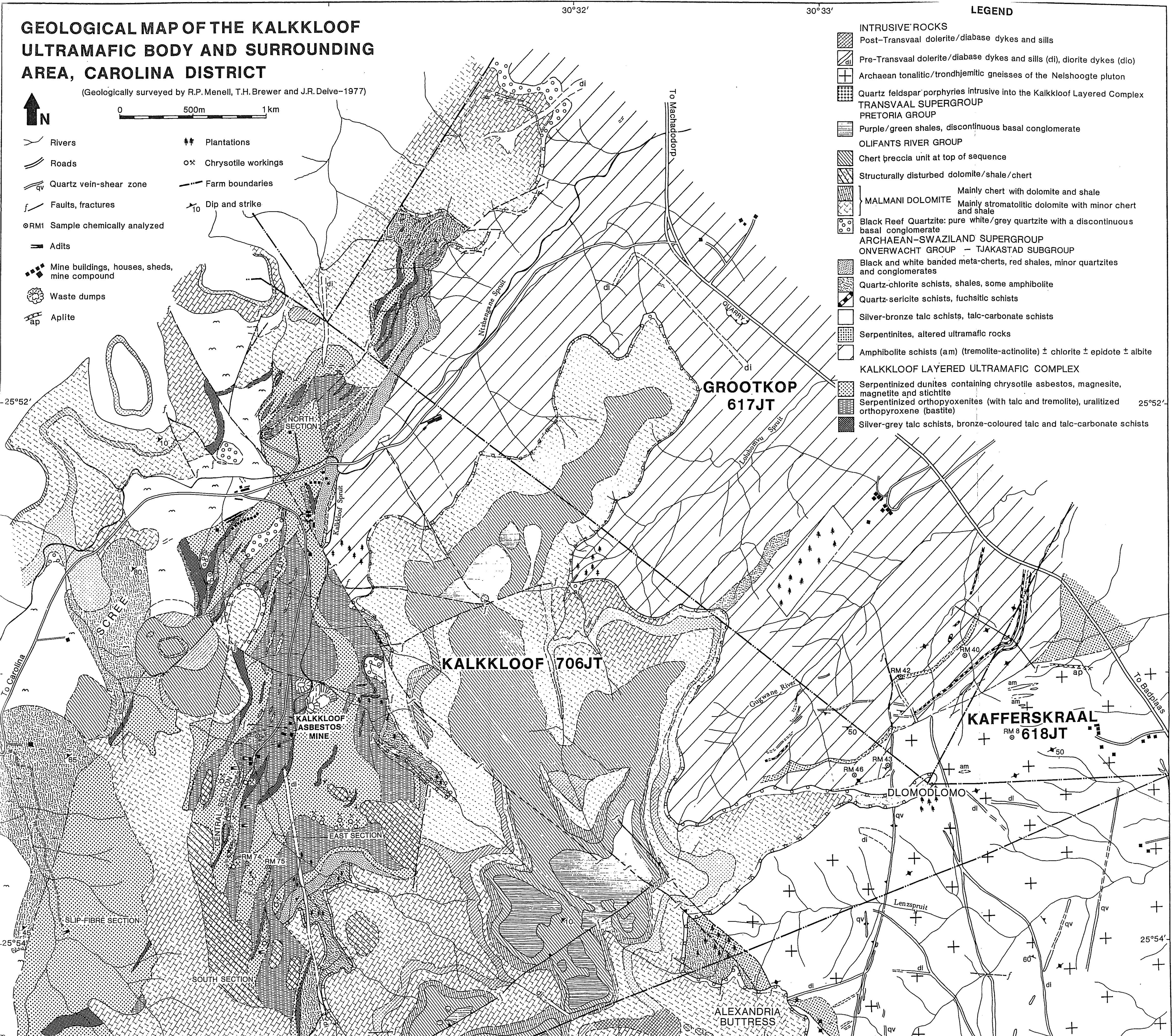
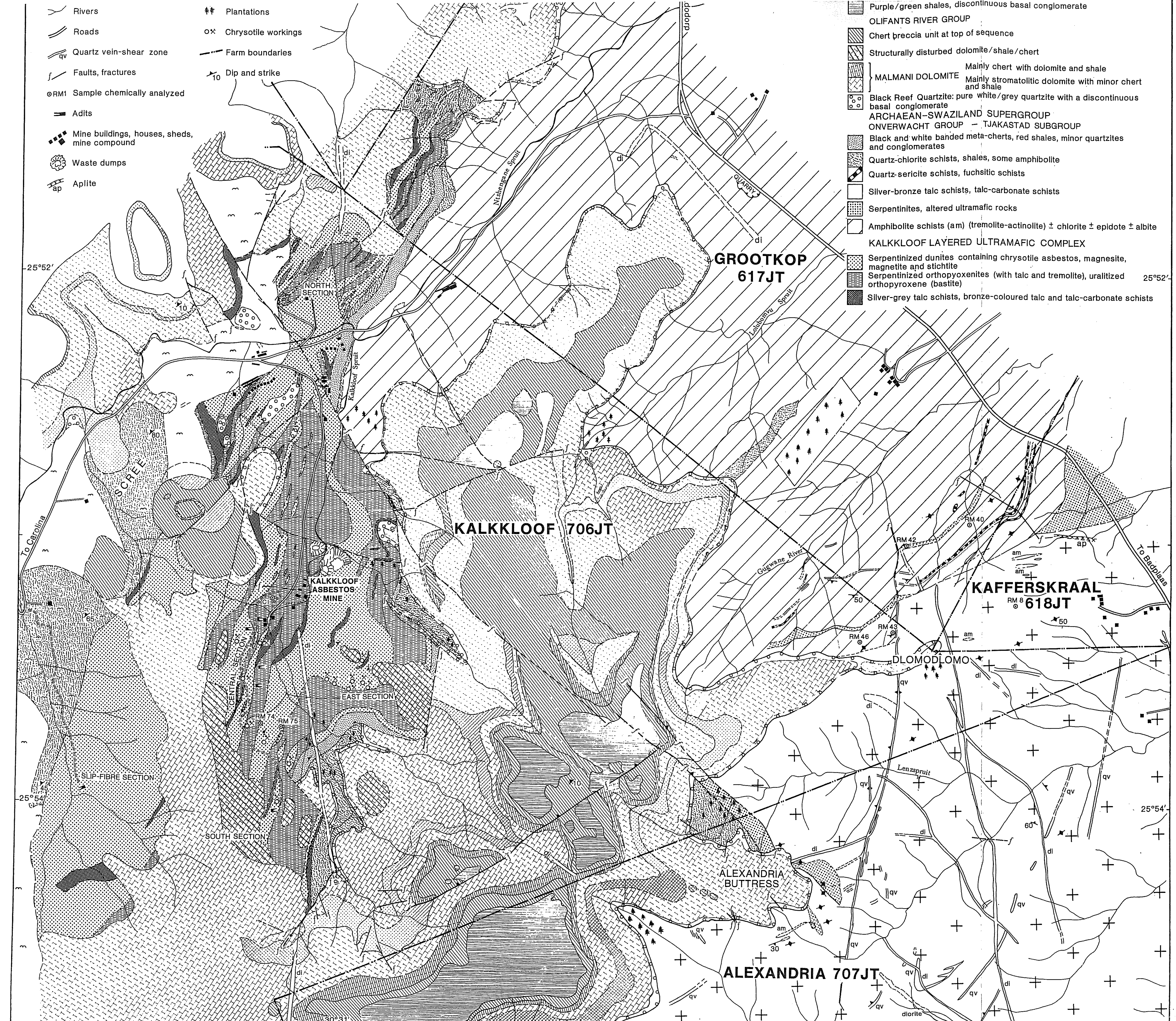
* *Figure 2 : Geological map of the Kalkkloof ultramafic body and surrounding area, Carolina District*


GEOLOGICAL MAP OF THE KALKKLOOF ULTRAMAFIC BODY AND SURROUNDING AREA, CAROLINA DISTRICT
(Geologically surveyed by R.P. Menell, T.H. Brewer and J.R. Delve–1977)
0 500m 1 km
N
Rivers
Roads
Quartz vein-shear zone
Faults, fractures
Sample chemically analyzed
Adits
Mine buildings, houses, sheds, mine compound
Waste dumps
Aplite
Plantations
Chrysotile workings
Farm boundaries
Dip and strike
LEGEND
INTRUSIVE ROCKS
Post–Transvaal dolerite/diabase dykes and sills
Pre–Transvaal dolerite/diabase dykes and sills (di), diorite dykes (dio)
Archaean tonalitic/trondhjemitic gneisses of the Nelshoogte pluton
Quartz feldspar porphyries intrusive into the Kalkkloof Layered Complex
TRANSVAAL SUPERGROUP
PRETORIA GROUP
Purple/green shales, discontinuous basal conglomerate
OLIFANTS RIVER GROUP
Chert breccia unit at top of sequence
Structurally disturbed dolomite/shale/chert
MALMANI DOLOMITE
Mainly chert with dolomite and shale
Mainly stromatolitic dolomite with minor chert and shale
Black Reef Quartzite: pure white/grey quartzite with a discontinuous basal conglomerate
ARCHAEAN–SWAZILAND SUPERGROUP
ONVERWACHT GROUP – TJAKASTAD SUBGROUP
Black and white banded meta-cherts, red shales, minor quartzites and conglomerates
Quartz-chlorite schists, shales, some amphibolite
Quartz-sericite schists, fuchsitic schists
Silver-bronze talc schists, talc-carbonate schists
Serpentinites, altered ultramafic rocks
Amphibolite schists (am) (tremolite-actinolite) ± chlorite ± epidote ± albite
KALKKLOOF LAYERED ULTRAMAFIC COMPLEX
Serpentinized dunites containing chrysotile asbestos, magnesite, magnetite and stichtite
Serpentinized orthopyoxenites (with talc and tremolite), uralitized orthopyroxene (bastite)
Silver-grey talc schists, bronze-coloured talc and talc-carbonate schists
30°32′
30°33′
25°52′
25°54′
To Machadodorp
To Carolina
To Badplaas
GROOTKOP 617JT
KALKKLOOF 706JT
KAFFERSKRAAL 618JT
KALKKLOOF ASBESTOS MINE
NORTH SECTION
CENTRAL SECTION
EAST SECTION
SOUTH SECTION
SLIP-FIBRE SECTION
SCREE
QUARRY
DLOMODLOMO
ALEXANDRIA BUTTRESS
Nhlengane Spruit
Kalkkloof Spruit
Lolubonvu Spruit
Gugwane River
Lenzspruit
RM 40
RM 42
RM 43
RM 46
RM 8
RM 74
RM 75



Rivers
Roads
Quartz vein-shear zone
qv
Faults, fractures
Sample chemically analyzed
RM1
Adits
Mine buildings, houses, sheds, mine compound
Waste dumps
Aplite
ap
Plantations
Chrysotile workings
Farm boundaries
Dip and strike
10
Purple/green shales, discontinuous basal conglomerate
OLIFANTS RIVER GROUP
Chert breccia unit at top of sequence
Structurally disturbed dolomite/shale/chert
MALMANI DOLOMITE
Mainly chert with dolomite and shale
Mainly stromatolitic dolomite with minor chert and shale
Black Reef Quartzite: pure white/grey quartzite with a discontinuous basal conglomerate
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Quartz-sericite schists, fuchsitic schists
Silver-bronze talc schists, talc-carbonate schists
Serpentinites, altered ultramafic rocks
Amphibolite schists (am) (tremolite-actinolite) ± chlorite ± epidote ± albite
KALKKLOOF LAYERED ULTRAMAFIC COMPLEX
Serpentinized dunites containing chrysotile asbestos, magnesite, magnetite and stichtite
Serpentinized orthopyroxenites (with talc and tremolite), uralitized orthopyroxene (bastite)
Silver-grey talc schists, bronze-coloured talc and talc-carbonate schists
GROOTKOP
617JT
KALKKLOOF 706JT
KAFFERSKRAAL
618JT
ALEXANDRIA 707JT
ALEXANDRIA BUTTRESS
DLOMODLOMO
KALKKLOOF ASBESTOS MINE
NORTH SECTION
CENTRAL SECTION
EAST SECTION
SOUTH SECTION
SLIP-FIBRE SECTION
SCREE
QUARRY
Kalkkloof Spruit
Ntshenga Spruit
Lolubomvu Spruit
Gugwane River
Lenzspruit
To Carolina
To Badplaas
RM 40
RM 42
RM 43
RM 46
RM 8
RM 74
RM 75
25°52′
25°54′
30°31′
diorite