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The Nature of Chrysotile Asbestos Occurrences in Southern Africa: A Review

C. R. Anhaeusser

Abstract

The principal chrysotile asbestos occurrences in Rhodesia, South Africa, and Swaziland are described, emphasis being placed on the regional geological settings and host rock stratigraphy of the mineralized areas. All the more important asbestos ore deposits in southern Africa are Archean in age (~2.5–3.5 b.y. old), being associated with ultramafic complexes occurring either as sill-like bodies in greenstone belts or as later cross-cutting intrusions.

The ultramafic bodies can be grouped into three varieties. These, in order of decreasing age, are: (1) the layered complexes associated with basaltic and peridotitic komatiite extrusives and forming part of the Lower Ultramafic Unit of southern African greenstone belts, (2) layered ultramafic bodies associated with the intermediate to acid volcanic rocks that constitute part of the Mafic-to-Felsic Unit of greenstone belts, and (3) ultramafic intrusive bodies that postdate the greenstone belts but which are still affected by Archean tectonic disturbances that arise from the emplacement of granites.

All the principal asbestos-bearing complexes show magmatic segregation into layered, often cyclically repetitive, differentiation sequences. These single or multicyclic sequences may consist of two or more of the following rock types: dunite, peridotite, harzburgite, lherzolite, wehrlite, bronzitite-enstatolite, websterite, gabbro, norite, and gabbroic anorthosite. Where fractional crystallization of the ultramafic magma has been most efficient, many layers at, or near, the base of the complexes comprise monomineralic cumulate phases. These commonly consist of dunites and Mg-rich orthopyroxenites. With increasing distance from the base, progressive Mg depletion and Fe enrichment of the successive layers take place. Although chrysotile asbestos may commonly be encountered in all serpentinized ultramafic rock types, optimum development of economically exploitable fiber generally occurs in dunites, peridotites, or harzburgites.

The Archean layered complexes were derived from magma of ultramafic composition in contrast to magmas of tholeiitic parentage that gave rise to the great stratiform intrusions like the Bushveld, Stillwater, and many others, including the Great Dyke in Rhodesia. The Great Dyke, unlike the others, however, acts as host to small chrysotile deposits developed in serpentinized dunites or harzburgites.

In addition to the asbestos mineralization found in the layered complexes, subordinate deposits, occurring in serpentinized dolomitic rocks associated with the ~2.0-b.y.-old Transvaal Supergroup, are briefly described.

Whereas faulting and fracturing is generally acknowledged as being largely responsible for the local development of asbestos fiber, examples from the southern African greenstone belts demonstrate that folding is often a dominant regional controlling factor in the localization of asbestos mineralization in ultramafic rocks.

Introduction

As a producer of chrysotile asbestos fiber, southern Africa ranks third in the world after Canada and the U.S.S.R. The bulk of the Canadian asbestos is derived from Paleozoic "alpine-type" masses of peridotite and pyroxenite intrusive into, and folded along with, the Cambrian to Devonian eugeosynclinal sediments of the Appalachian belt in the Thetford district of the Eastern Townships of Quebec. In the U.S.S.R., the principal asbestos-producing area is located in the Bajenova district of the Urals, in late Precambrian to Paleozoic orogenic terrain between the Russian and Siberian Platforms.

By contrast, almost the entire southern African production emanates from Archean ultramafic-mafic complexes, most of which are associated with the ancient greenstone belts on the Rhodesian and Kaapvaal Cratons. While chrysotile asbestos in rocks of Archean age is by no means unique to southern Africa, it appears that the deposits located in the Superior Province of Canada, the Yilgarn and Pilbara divisions of the Western Australian Shield, and elsewhere are subordinate to their southern African counterparts in terms of production and size.

The objectives of this paper are briefly to review the geological settings and regional controlling factors

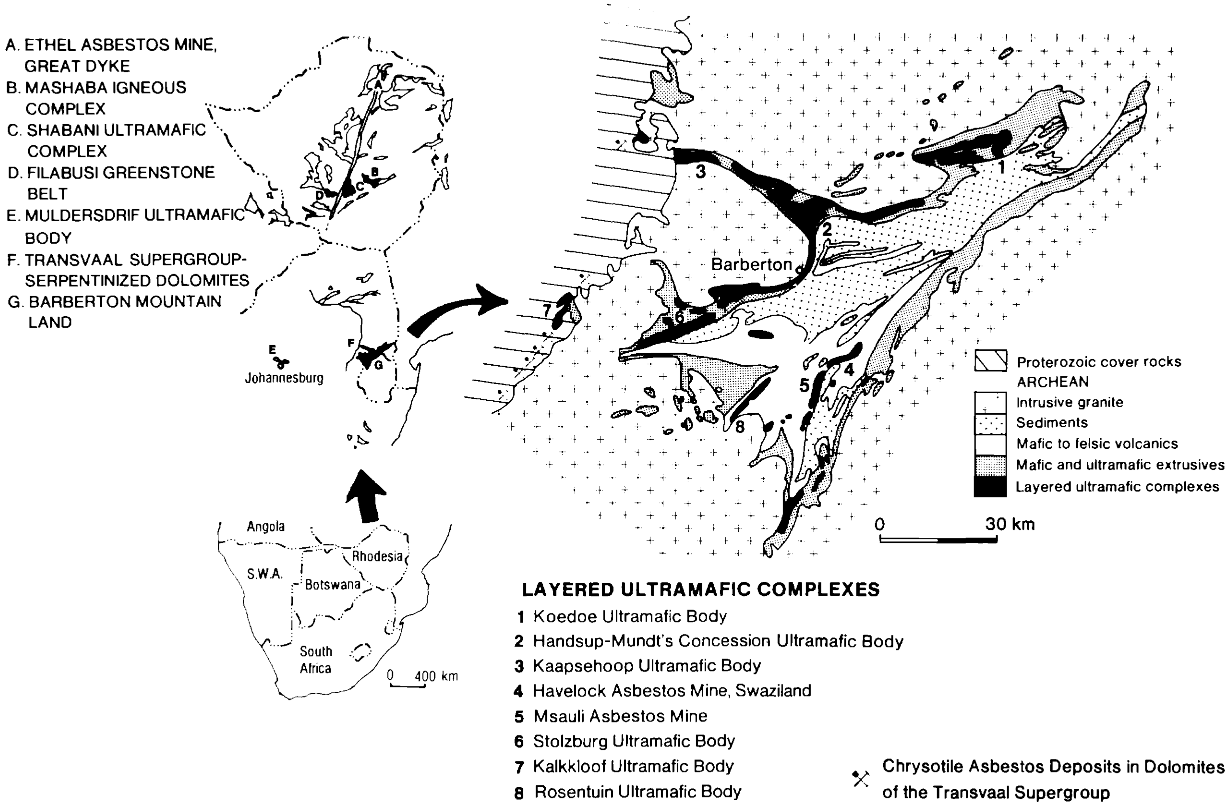

FIG. 1. Map showing the distribution of the principal chrysotile asbestos-producing regions in Rhodesia, South Africa, and Swaziland.

responsible for the development of chrysotile asbestos in southern Africa. It is not the intention to enter here into lengthy discussions on the nature and origin of serpentinites, the mineralogy of serpentine minerals or chrysotile asbestos fiber growth mechanisms, as these aspects have received adequate coverage by a great many investigators including Graham (1917), Taber (1917), Benson (1918), Hess (1933), Cooke (1937), Bowen and Tuttle (1949), Zussman (1945), Riordon (1955), Nagy and Faust (1956), Whittaker and Zussman (1956), Chidester (1962), Laubscher (1964, 1968), van Biljon (1964), Jahns (1967), and many others.

Emphasis in this review is placed, rather, in detailing the chrysotile asbestos host rock stratigraphy, geochemical characteristics, and structural settings of the principal ore deposits in the Archean greenstone belts of Rhodesia, South Africa, and Swaziland and, for completeness, in describing briefly the geological controls of chrysotile asbestos occurrences associated with ultramafic rocks of the Great Dyke in Rhodesia and the serpentinized dolomites of the Transvaal Supergroup.

The main chrysotile asbestos-producing regions in southern Africa are shown in Figure 1, while descriptions of the individual localities will be given in the sections that follow.

General Geological Setting of the Archean Asbestos Deposits

Archean greenstone belt stratigraphy in southern Africa can, very broadly, be grouped into three main subdivisions. The lowermost assemblages generally encountered consist of a succession of alternating ultramafic and mafic lavas together with subordinate felsic, often aluminous, schists. This sequence of rocks is collectively referred to as the *Lower Ultramafic Unit* and embraces the pre-Sebakwian and Sebakwian successions of Rhodesia and assemblages correlated with the lower three formations of the Onverwacht Group of the Swaziland Supergroup in South Africa and Swaziland.

Stratigraphically higher in the successions the rocks generally consist of cyclically alternating mafic and intermediate to acid volcanics, referred to collectively as the *Mafic-to-Felsic Unit.* Assemblages falling into this category include rocks of the Bulawayan Group in Rhodesia and the upper three formations of the Onverwacht Group in South Africa and Swaziland.

Overlying the essentially volcanic assemblages just described are rocks comprised mainly of detrital sediments with subordinate volcanic and pyroclastic members. These rocks, which can be further subdivided into argillaceous and arenaceous phases, are referred to as the *Sedimentary Unit.* In South Africa and Swaziland, the Sedimentary Unit embraces both the argillaceous Fig Tree Group and the arenaceous Moodies Group. In Rhodesia the distinction is less clear with the Shamvaian Group consisting mainly of arenaceous sediments. Subordinate argillaceous sediments are present in this succession as well as in the underlying Bulawayan Group.

In several localities within the Lower Ultramafic Unit and, to a lesser extent, in the Mafic-to-Felsic Unit, a number of layered differentiated ultramafic pods and sills are developed. It is in many of these intrusive ultramafic complexes that the chrysotile asbestos fiber of economic significance is to be found. In addition to the layered complexes, which appear to represent sills that were intruded penecontemporaneously within the developing ultramafic and mafic lava successions, there are intrusive ultramafic bodies, like the Mashaba Igneous Complex in Rhodesia, which postdate the greenstone belts but which are, nevertheless, deformed by the emplacement of Archean granites.

Recent studies in the Barberton Mountain Land, South Africa, both by the writer (Anhaeusser, 1969; and in prep.) and Viljoen and Viljoen (1969a, b), have provided new information relating to the layered ultramafic complexes, the localities of which are depicted in Figure 1. These findings supplement the earlier geological descriptions of the chrysotile asbestos occurrences in the area provided by Hall (1918, 1921, 1930) and van Biljon (1959, 1964).

Layered Ultramafic Complexes of the Barberton Mountain Land

The Stolzburg ultramafic body

The Stolzburg body occurs in the Nelshoogte schist belt which, in turn, is located in the extreme southwestern portion of the Barberton greenstone belt (Fig. 1). The successions in the area form part of the Onverwacht Group and consist of a well-layered sequence of basaltic lavas, interlayered with peridotitic lavas and a few minor siliceous schist horizons. Over 90 percent of the rocks in the area consist of komatiitic or tholeiitic basalts, whereas extrusive peridotitic komatiites and altered felsic volcanics make up the remainder of the succession, classified as part of the Lower Ultramafic Unit. The Stolzburg differentiated body is considered to have been emplaced penecontemporaneously with the surrounding Onverwacht lavas as a sill, the whole sequence subsequently being deformed and metamorphosed by the intrusion of Archean diapiric tonalite gneiss plutons.

The Stolzburg body, which exceeds 16 km in length and averages 1 km in width, is bounded on the northwest and southeast by two major faults (Fig. 2). The vertically to subvertically dipping formations consist of a cyclic succession of serpentinized dunite and orthopyroxenite layers near the base, with serpentinized harzburgites and peridotites higher in the sequence, the latter commonly associated with layers of gabbro or norite, and, in places, gabbroic to noritic anorthosites. In the central portion of the complex are rocks that have undergone lime metasomatism to form rodingites, the latter occurring as dikes cutting serpentinized dunites and as conformable lenses or sheets replacing ultramafic and gabbroic rocks.

At least twelve cycles are present in the Doyershoek mine area, while in the Stolzburg and Sterkspruit mine areas to the southwest, only approximately half the succession is present, the upper cycles being truncated by a fault cutting obliquely across the complex. The lower members of the layered sequence occur on the northwestern side of the body and consist of alternating serpentinized dunites (olivine cumulates) and generally altered but, in places, remarkably fresh orthopyroxenite layers (bronzite cumulates). The upper half, on the southeastern side of the body, consists mainly of serpentinized harzburgites and peridotites, gabbros, norites, and anorthositic gabbros.

The geochemical characteristics of the more important rock types encountered from base to top of the layered sequence, as well as from the "ore zone" serpentinites, are presented in Table 1. The serpentinized dunites, nearer the base of the complex, are the host rocks to the chrysotile asbestos deposits, the latter having been described by Hall (1930), van Biljon (1959, 1964), and Viljoen and Viljoen (1969b). A strong mineralization control is evident, with exploitable asbestos fiber occurring in dunites affected by prominent cross faulting and intraformational shear deformation. The three deposits that have been mined in the area are all located in zones disturbed by prominent cross faulting, the latter presumably caused by differential transcurrent movements along the regional bounding faults. In the Stolzburg mine area faulting has also been responsible for the inflection of the cyclic dunite and orthopyroxenite layers, the latter forming, in part, a southward-plunging synclinal fold. The asbestos mineralization is located in and around the hinge of the fold and on the southwestern limb of the structure. Optimum fiber development occurs at the

TABLE 1. Chemical Analyses of Archean Layered Ultramafic Complexes and Chrysotile Asbestos Occurrences in the Barberton Mountain Land

	STOLZBURG ULTRAMAFIC BODY							KOEDOE ULTRAMAFIC BODY					
	1	2	3	4	5	6	7	8	9	10	11	12	13
					V177	V178a	V178b	V40	KJ50	K38	Au21	KR45	V36A
SiO_2	40.28	40.43	52.94	52.66	36.36	38.41	41.70	42.03	-	55.15	53.60	53.22	44.57
Al_2O_3	1.75	3.23	1.50	9.32	2.37	2.79	0.82	3.32	-	1.68	3.45	3.01	20.09
Fe_2O_3	4.55	3.78	0.94	1.31	9.66	4.79	1.92	2.21	6.96	2.08	0.38	Nil	0.30
FeO	3.55	4.81	6.19	7.47	0.57	0.14	0.0	5.80	0.74	6.13	8.92	6.18	2.30
MgO	35.63	33.93	30.65	13.13	37.33	40.05	40.41	32.66	34.05	30.67	26.09	20.79	12.40
CaO	0.70	2.18	1.95	9.94	0.10	0.12	0.12	1.11	0.36	2.22	3.88	14.26	15.39
Na_2O	0.03	0.08	0.05	2.30	0.10	0.28	0.62	0.14	0.05	0.13	0.31	0.25	0.55
K_2O	0.01	0.02	0.09	0.21	0.10	0.15	0.22	0.03	0.03	0.04	0.13	0.06	0.03
TiO_2	0.08	0.13	0.08	0.42	0.05	0.06	0.04	0.14	-	0.07	0.07	0.08	0.01
P_2O_5	0.03	0.04	0.03	0.08	0.04	0.04	0.02	0.01	-	Nil	0.01	0.05	0.01
MnO	0.12	0.14	0.18	0.14	0.06	0.06	0.06	0.10	-	0.18	0.22	0.23	0.07
CO_2	1.60	0.30	0.13	0.20	0.13	0.13	0.10	-	-	-	-	-	-
H_2O	10.94	10.33	4.61	2.55	13.26	13.58	14.58	19.99	-	0.52	0.18	0.34	3.12
Total					100.13	100.60	100.51	98.00		98.87	97.24	98.47	98.85

1. Serpentinized dunite. Average of 5 analyses.
2. Serpentinized peridotite-harzburgite. Average of 8 analyses.
3. Orthopyroxenite. Average of 20 analyses.
4. Metagabbro-norite. Average of 10 analyses.
5. Dark green serpentinite from core of "boulder".
6. Light green serpentinite - outer shell of dark green "boulder"
7. Chrysotile asbestos in seams (13 mm) in light green serpentinite.
8. Serpentinized peridotite (chill zone).
9. Serpentinized dunite/peridotite.
10. Orthopyroxenite (lower portion of zone).
11. Orthopyroxenite (upper portion of zone).
12. Websterite.
13. Gabbro/norite.

Analyses 1-4 - analysts : National Institute for Metallurgy, Johannesburg, and Durham University, Durham, England.
Analyses 5-6 (van Biljon, 1959)
Analyses 8-13 (Viljoen and Viljoen, 1969a).

base of serpentinized dunite layers where these rocks abut against underlying, more resistant, orthopyroxenite units of previous dunite-orthopyroxenite cycles. During deformation, which involved both faulting and folding, differential intraformational movement took place between the serpentinized dunites and the more competent orthopyroxenite layers. This produced dilationary zones wherein fiber growth took place, as is witnessed by the many quarries located in the "ore zone" serpentinites southwest of the central portion of the mine (Fig. 2).

Chrysotile fiber is frequently encountered in the serpentinized harzburgitic and peridotitic rocks higher in the Stolzburg succession but is never abundant and has nowhere been mined.

The serpentinization of the dunites, harzburgites, and peridotites is accompanied by the migration of certain components of the rock (notably Si, Al, Fe, Mg, Ca, and Na; Table 1). Chrysotile fiber appears to be best developed in serpentinites deficient in Fe and Al, a feature confirming the studies of Nagy and Faust (1965), who presented data showing that chrysotiles contained between 1.9 and 2.9 percent Al_2O_3 or Fe_2O_3, whereas antigorite contained between 2.9 and 6.5 percent Al_2O_3 or Fe_2O_3. The iron liberated from the serpentinized "ore zone" olivine cumulates of the Stolzburg body frequently occurs as magnetite seams filling shear zones. Magnetite has also been reported intergrown with chrysotile fiber veins in subeconomic "ore zone" serpentinites, northeast of the Sterkspruit mine (Viljoen and Viljoen, 1969b). Silica migration in the Stolzburg body gives rise to the development of veins of opal, the latter associated with chrysotile and magnetite at the Doyershoek mine (van Biljon, 1964) and in the area northeast of the Sterkspruit mine.

The Koedoe ultramafic body

Interlayered with Onverwacht Group basaltic and peridotitic komatiites, tholeiitic pillow lavas, tuffs, and subordinate chert horizons on the northern flank of the Barberton Mountain Land are a number of layered ultramafic bodies that have been described by Viljoen and Viljoen (1969a). Prominent in this area are economic magnesite deposits associated with cumulate olivine-rich rocks (dunites and dunite-peridotites). Also in this area is the Koedoe ultramafic body (Fig. 1), which contains the only chrysotile asbestos deposit to have been exploited in the

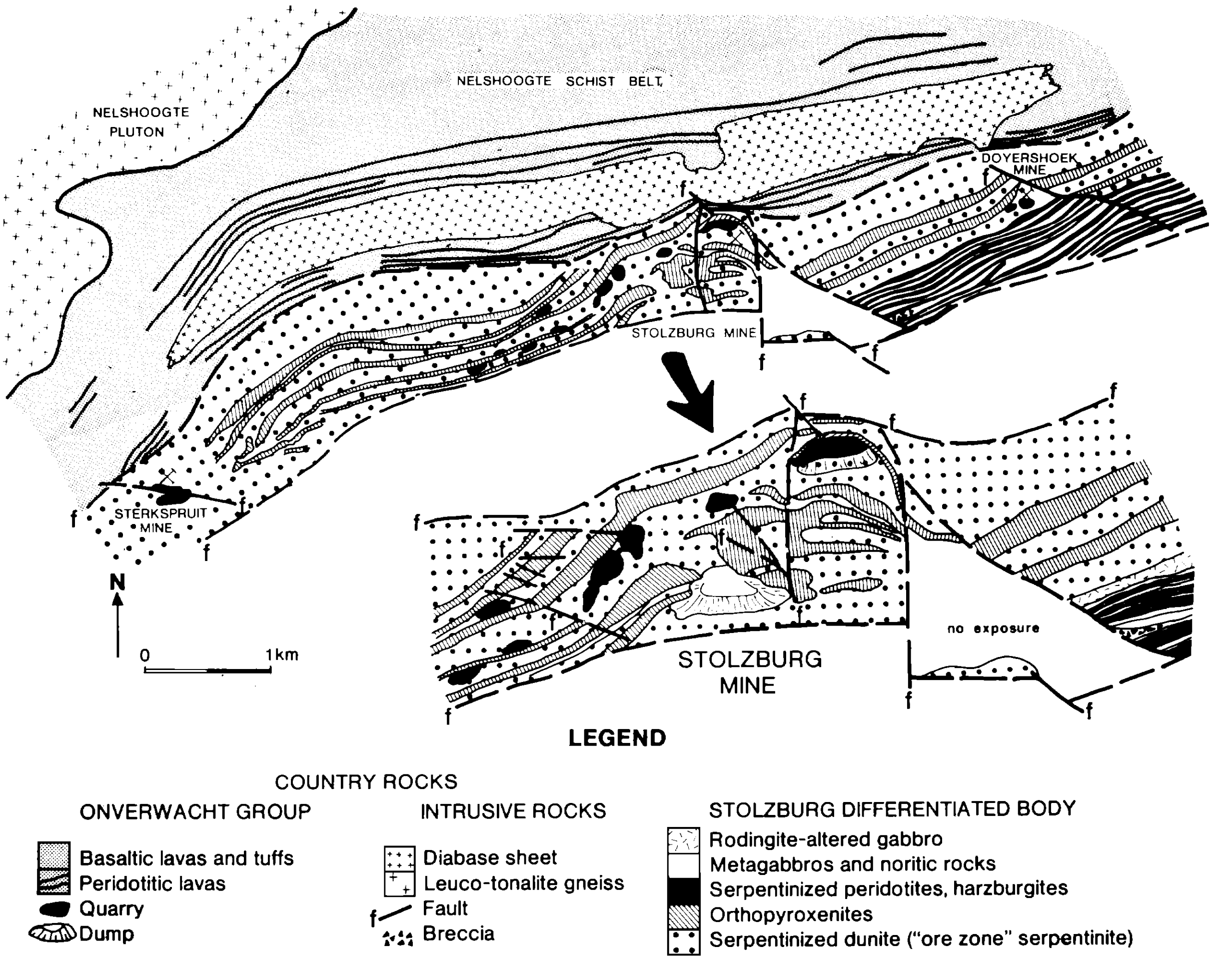

FIG. 2. Geologic map of portion of the Stolzburg layered ultramafic body showing the distribution of asbestos mineralization at dunite-orthopyroxenite contacts and associated with cross faults. Folding accompanies the faulting in the Stolzburg mine area.

region, namely the Three Cats mine (formerly the Barberton Chrysotile Asbestos mine).

The layered sequence of the Koedoe body (Fig. 3) consists of a serpentinized chill-zone peridotite at the base, followed by a zone of dunite and olivine peridotite, the latter unit generally serpentinized but displaying relic cumulus olivine crystals in places. The dunite-peridotite zone is, in turn, overlain by thin zones of orthopyroxenite (cumulus bronzite), clinopyroxenite (cumulus websterite), and cumulus anorthositic gabbros and norites, the latter rock types terminating the lower differentiated cycle. The anorthositic gabbro/norite layer is succeeded by a second, or upper, dunite-peridotite zone similar to that of the lower cycle but containing, in addition, harzburgitic and wehrlitic phases. In Table 1, the geochemical characteristics of some of the more important rock types encountered in the Koedoe body are listed. A clear differentiation trend is evident which can be closely correlated with the proportion and composition of the mineral phases in each zone (Viljoen and Viljoen, 1969a).

The Koedoe body differs little in its geochemical characteristics from other layered ultramafic complexes in the immediate vicinity. It has, however, been folded into a tight syncline which plunges approximately 60 degrees to the northeast and has a well-developed north limb and, by comparison, a poorly formed, structurally disturbed, south limb. The asymmetrical syncline is situated immediately north of a major left-lateral transcurrent fault which appears to have acted as a detachment plane along and adjacent to which the layered complex was deformed.

The lower and upper serpentinized dunite-peridotite layers constitute the potential "ore zone" serpentinites with asbestos prospects occurring at a number of localities around the structure. It is, however, only in the hinge of the fold that economic fiber has developed. According to Viljoen and Viljoen (1969b) the orebody, which is confined to the lower dunite-peridotite layer, varies between 10 and 30 m thick, is tabular in shape, and plunges in the same direction as the regional fold. The fiber is developed in a stockwork of tensional fractures which formed during the development of the fold. Features of the deposit include the presence of ribbon fiber near the footwall and hanging wall of the orebody and the extensive development of magnetite seams (van Biljon, 1964). In places, magnesite is also associated with the asbestos fiber.

Although asbestos mineralization is also present in the hinge zone of the upper serpentinized dunite-peridotite layer it is not of economic grade.

Chrysotile asbestos occurrences in the Jamestown schist belt

To the north of Barberton, and forming an arcuate schist belt wedge striking almost at right angles to the regional trend of the main body of the Barberton Mountain Land to the southeast, is the Jamestown schist belt. The formations caught up in this tightly folded synclinorial structure are composed mainly of a variety of mafic and ultramafic assemblages belonging to the lower part of the Onverwacht Group (Anhaeusser, 1972a). The schist belt is flanked on the south by an intrusive diapiric hornblende tonalite gneiss pluton and on the north by a wide variety of intrusive granites, gneisses, and migmatites. The Jamestown schist belt has undergone a complex evolutionary history involving polyphase deformation and metamorphism. Numerous folds, faults, and shear zones occur along the entire length of the belt which is exposed for approximately 35 km before it disappears beneath younger cover rocks in the northwest.

Prominent within the mafic and ultramafic volcanic successions are a number of layered differentiated ultramafic bodies, most of which contain chrysotile asbestos fiber. It is, however, in only two of these bodies that economically exploitable fiber has been mined. These asbestos deposits occur in layered ultramafic complexes located at the two extremities of the Jamestown schist belt, namely, in the Kaapsehoop ultramafic body and in the Handsup-Mundt's Concession ultramafic body (Fig. 1)

The Handsup-Mundt's Concession ultramafic body: Several major structures occur in the Jamestown schist belt but the most impressive of these are the two prominent folds located west of Noordkaap

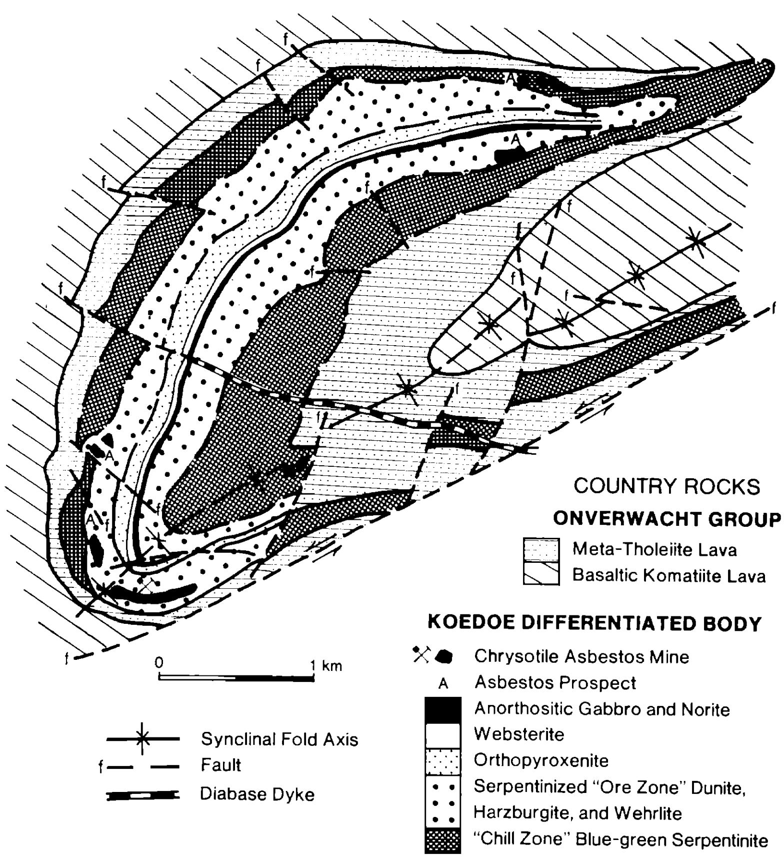

FIG. 3. Distribution of chrysotile asbestos mineralization in the synclinally folded Koedoe layered ultramafic body. (Adapted from Viljoen and Viljoen, 1969a.)

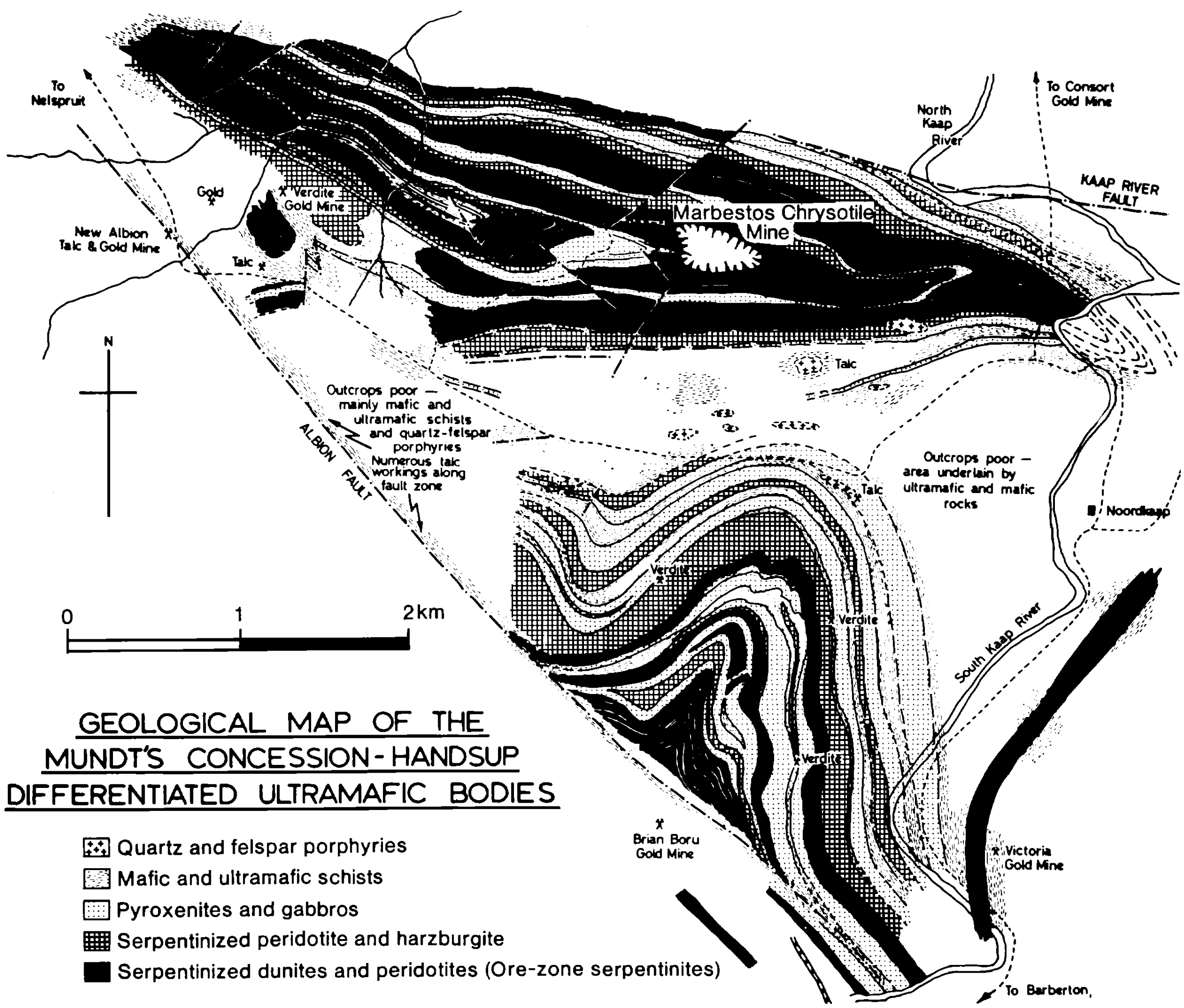

FIG. 4. Map showing the occurrence of asbestos mineralization in the fold hinge of the Mundt's Concession ultramafic body. Also depicted is the disharmonic fold of the Handsup layered ultramafic complex.

(Fig. 4) and which constitute the Handsup and Mundt's Concession layered ultramafic complexes described by Anhaeusser (1969). These bodies take the form of two major anticlinal structures separated by a poorly exposed synclinal divide. The Handsup body represents a major disharmonic fold developed to the north of the Albion fault, the latter representing a detachment plane which behaved as a left-lateral transcurrent dislocation. The Mundt's Concession body strikes approximately east-west although the fold axis is gently warped about the north-northeastern bulge of the Handsup fold. Although exposure is poor in the synclinal divide, the two structures are believed to have been linked prior to deformation.

The ultramafic bodies consist of vertically to subvertically dipping layered successions comprising a minimum of four differentiation cycles. Each cycle commences with a magnesium-rich ultramafic unit which is generally totally serpentinized. The Mg-rich layers consist mainly of serpentinized dunite, peridotite, or harzburgite and are overlain by pyroxenites (websterite, diopsidite, and diallagite, now largely altered to amphibolites) and metagabbroic rocks containing, in places, anorthositic phases. Deformation and metamorphism have altered many of the rocks to a variety of talc, talc-carbonate, tremolite-actinolite, and chloritic schists. In some cycles the full range of differentiation products may be present, while in others, one or more of the units may be missing. Geochemical analyses of the more important rock types encountered in these ultramafic bodies are listed in Table 2. A clear differentiation trend exists from base to top of the complexes. This is particularly evident in the Handsup body (Fig.

TABLE 2. Chemical Analyses: Layered Archean Ultramafic Complexes and Chrysotile Asbestos Occurrences in South Africa and Swaziland

	HANDSUP - MUNDT'S CONCESSION ULTRAMAFIC BODY				HAVELOCK ASBESTOS MINE, SWAZILAND			MULDERSDRIF ULTRAMAFIC COMPLEX			
	1	2	3	4	5	6	7	8	9	10	11
	CAN30	CAN 9	CAT40D	CAN10	V14	V22a	V22b	VW 37	VW 26	VW 30	VW 27
SiO_2	40.23	42.44	54.97	54.30	36.91	33.82	39.96	40.00	48.10	45.84	48.71
Al_2O_3	2.20	2.34	3.65	7.14	3.52	1.57	0.85	2.84	1.05	13.50	15.36
Fe_2O_3	4.35	2.62	0.70	1.22	6.87	3.91	3.67	5.45	1.21	2.36	1.83
FeO	2.39	5.24	6.53	7.47	0.14	0.07	0.07	1.15	3.81	10.52	9.14
MgO	36.73	31.89	16.37	13.41	39.07	44.49	40.66	37.52	31.59	7.60	8.18
CaO	0.60	2.83	14.24	11.08	0.36	0.10	0.24	0.26	4.48	15.56	10.10
Na_2O	0.08	0.08	1.25	2.68	0.15	0.15	0.30	0.06	0.04	0.61	0.35
K_2O	0.02	0.02	0.03	0.10	0.12	0.12	0.12	0.10	0.10	0.20	1.72
TiO_2	-	tr	0.24	0.40	0.05	0.08	0.08	0.06	0.05	1.00	0.75
P_2O_5	0.01	0.02	0.01	0.02	0.08	0.06	0.06	0.05	0.06	0.08	0.10
MnO	0.10	0.13	0.18	0.18	0.09	0.05	0.06	0.09	0.26	0.24	0.19
CO_2	0.87	0.66	0.16	-	0.18	0.11	0.13	0.11	0.14	0.07	0.16
H_2O	11.92	10.48	1.63	2.12	13.00	15.52	13.46	12.21	8.56	2.47	3.24
Total	99.33	98.58	99.96	100.03	100.54	100.05	99.66	99.90	99.45	100.05	99.83

1. Serpentinized dunite/peridotite.
2. Serpentinized harzburgite.
3. Pyroxenite (websterite).
4. Metagabbro.
5. Dark green serpentinite (pyroxenite ? - hangingwall of Havelock orebody).
6. Light green serpentinite with chrysotile veins. Average ore body rock (dunite).
7. Good quality (19 mm) chrysotile fiber in light green serpentinite (dunite).
8. Serpentinized dunite/peridotite.
9. Serpentinized harzburgite/wehrlite.
10. Metagabbro.
11. Metagabbro.

Analyses 1-4 (Anhaeusser, 1969), Analyses 5-7 (van Biljon, 1969), Analyses 8-11. Analysts : National Institute for Metallurgy, Johannesburg.

4) which shows Mg depletion and Fe enrichment upward in the layered sequence.

Chrysotile asbestos mineralization is confined to the dunites or the olivine peridotites, being virtually absent in the harzburgitic rocks. Fiber is developed mainly in the cores of both folds but has been commercially exploited only at the Marbestos mine, located in the hinge zone of the Mundt's Concession body in "ore zone" serpentinized dunite-peridotites. The asbestos fiber mined is mainly of no. 7 grade (short fiber, 1-2 mm in length) and occurs in a stockwork of tension veins located near to, and in, the fold axis. The low-grade deposit probably results from the fact that the Mundt's Concession-Handsup bodies have not undergone the same degree of magmatic differentiation as some of the other ultramafic complexes in the Barberton area. Consequently the "ore zone" serpentinites have been derived mainly from olivine peridotites rather than from dunites (Viljoen and Viljoen, 1969b).

The Kaapsehoop ultramafic body: Situated at the northwest end of the Jamestown schist belt and extending beneath the Proterozoic cover rocks of the Transvaal escarpment is the Kaapsehoop ultramafic body (Fig. 1), in which are located the New Amianthus, Munnik Myburgh, and Sunnyside/Star asbestos mines (Fig. 5). The earliest comprehensive account of these asbestos occurrences is that given by Hall (1930), while in later years the deposits were described by van Biljon (1959, 1964). Investigations in the Jamestown schist belt by the writer (Anhaeusser, 1969; 1972a) led to the reclassification of the formations in the area into the lower division of the Onverwacht Group.

The Kaapsehoop ultramafic body is similar to the lower division of the Stolzburg body described earlier in that it consists essentially of a cyclic development of serpentinized dunite and orthopyroxenite layers, the latter having been referred to previously as "light green serpentinites" and "hard blue serpentinites" respectively (Visser et al., 1956; van Biljon, 1964). These alternating serpentinized dunite-orthopyroxenite layers are best developed on the southern limb of the major fold structure which constitutes the Kaapsehoop body as a whole. Higher in the succession, to the east of the Munnik Myburgh mine, metagabbroic rocks make an appearance. Further masses of this type also occur on the structurally disturbed northern limb of the main fold.

Several major faults slice the Kaapsehoop ultramafic body into a number of compartments which tend to distort and disguise the folded nature of the complex. Zones of talc-carbonate schist between the gabbroic masses, particularly prominent on the northern limb of the body, probably represent sheared and steatized ultramafic rocks that were initially dunitic or peridotitic in composition. The structure represents a disturbed syncline with an east-west fold axis and a south limb dipping northward at intermediate angles of between 30 and 60 degrees. The fold plunges to the east at approximately 45 degrees.

Two of the three asbestos mines in the area (New Amianthus and Munnik Myburgh) are located in "ore zone" serpentinites occupying the hinge zone of the folded ultramafic body. The Sunnyside/Star mine, by contrast, occurs along the southern, relatively undeformed, limb of the syncline. The asbestos fiber generally occurs in the altered dunites where these are in contact with the altered pyroxenites. Differential movements between competent orthopyroxenites and less competent dunites are responsible for some of the orebodies (e.g., Sunnyside/Star), although the effects of the faulting in the area must also be regarded as a contributing factor aiding fiber development. According to van Biljon (1964) the "ribbon" nature of the fiber in parts of the Munnik Myburgh mine is replaced by a stockwork of asbestos seams in the vicinity of the fault passing through the mine area.

It is noteworthy that the chrysotile fiber is not confined to the basal portions of the dunite zones alone, being developed instead at both the lower and upper contacts of this rock type, where it occurs adjacent to the altered orthopyroxenites. An additional feature of this asbestos-producing area is the development, in the New Amianthus mine, of two distinct fiber horizons (Hall, 1930). The first of these occurs at the contact between green and blue serpentinite (in the manner described above), while the second, known locally as the "Ribbon Line", strikes north-south and is restricted to the contact zone between the base of the Proterozoic cover sequence of quartzites and shales and the underlying serpentinite. Fiber is formed across both the light-green and dark blue-green varieties but occurs in payable quantities only where the light-green serpentinite is in contact with the sediments. Although most of the "Ribbon Line" fiber zone has now been mined out, Hall (1930) recorded that over a 2.13 m face, the upper 0.91 m contained 45 seams with fiber length varying between 6 and 12 mm. The lower 1.22 m contained 120 seams varying between 1.6 and 6 mm in length. Fiber lengths of between 50 and 152 mm were found in places and at one point

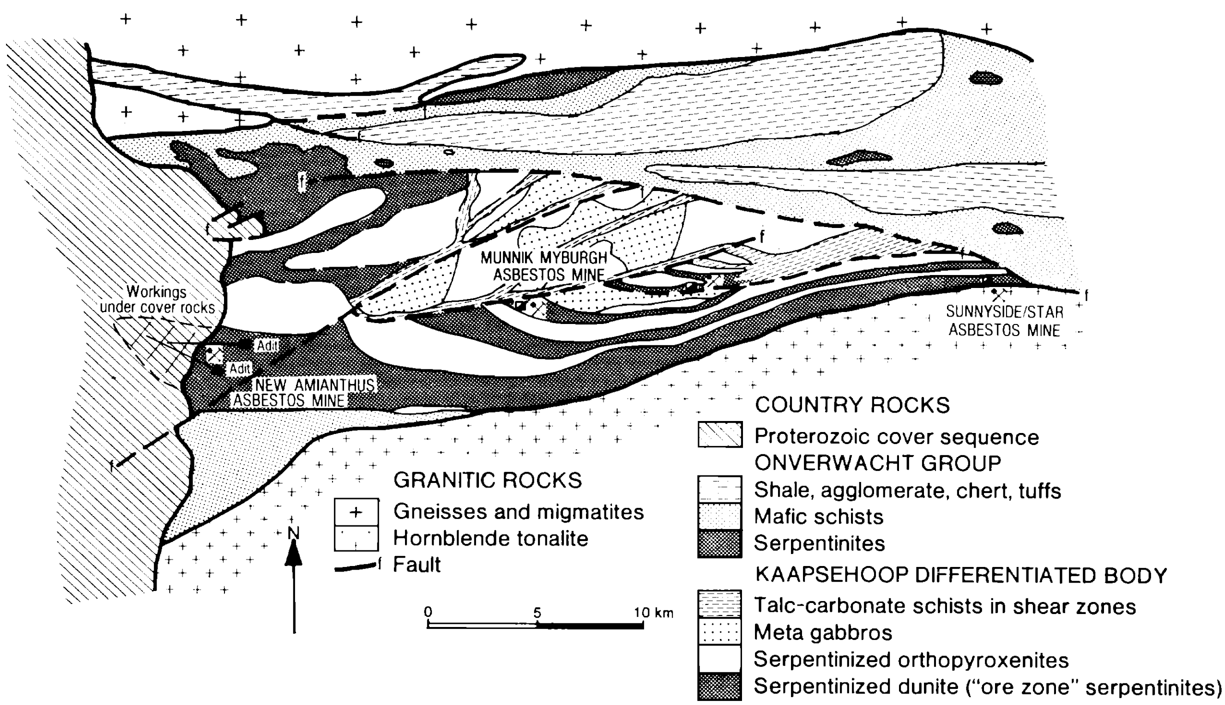

FIG. 5. Geologic map of the Kaapsehoop differentiated body showing the distribution of the principal chrysotile asbestos deposits in the area. The mineralization is associated with folding and faulting and occurs at dunite-orthopyroxenite contacts. (Modified after Visser et al., 1956; and van Biljon, 1964.)

cross-fiber measuring 218 mm in length was recorded. "Ribbon" fiber seams are not restricted to the "Ribbon Line" alone but were also mined from fiber horizons at the contacts between the serpentinized dunites and the altered orthopyroxenites. The origin of the "ribbon" fiber has not adequately been resolved (van Biljon, 1964) but it appeals to the writer to link its development to the differential movements affecting "ore zone" serpentinites and rocks of differing competencies. As pointed out by van Biljon (1964), the New Amianthus "Ribbon Line" fiber could only have developed after the deposition of the Proterozoic sedimentary cover sequence and is thus clearly later in age than the fiber horizons developed in other sections of this mine or in the other mines in the area. The eastern escarpment formations have been involved in considerable basin edge faulting, resulting in the development of horsts and grabens and the intrusion of dikes and sills. In addiiton, intrastratal shearing is common in the area (Button, 1974) and these deformations might have been contributory factors to the development of the tensional conditions necessary for fiber growth to have taken place.

The Havelock and Msauli asbestos deposits

Two of the largest chrysotile asbestos deposits in southern Africa, namely the Havelock and the Msauli orebodies, occur in the southeastern portion of the Barberton Mountain Land, in successions now classified in the Swartkoppie Formation of the Onverwacht Group (Viljoen and Viljoen, 1969b; Hunter and Jones, 1969). In this region, the Swartkoppie assemblages straddle the Transvaal-Swaziland border and constitute the uppermost member of the Mafic-to-Felsic Unit outlined earlier. The main components of the Swartkoppie Formation stratigraphy, in the area of the two mines, include green and gray schists derived from basaltic to intermediate volcanic rocks, banded cherts, siliceous ferruginous cherts, and a number of serpentinite pods or lenses, which have previously been regarded as being of later intrusive origin (Pretorius, 1961; van Biljon, 1964; Mackenzie, 1965). Mapping by the Swaziland Geological Survey (Hunter and Jones, 1969) and studies by Viljoen and Viljoen (1969b) indicate that all of the serpentinite pods occur in the same stratigraphic position within the Swartkoppie Formation, between cherts and related sediments which, in most cases, form the immediate footwalls and hanging walls of the orebodies. The serpentinized ultramafic pods are now considered to represent parts of a once continuous or nearly continuous differentiated sill emplaced penecontemporaneously with the remaining Swartkoppie rocks and conformable with the latter.

The most recent regional geological mapping in the Havelock-Msauli mine areas is summarized in Figure 6. Despite the fact that the region has been intensely folded and faulted, the "ore zone" serpentinites of the Havelock mine can be traced intermittently westward where they eventually link up with the asbestos deposits of the Msauli mine 7 km away.

On the simplified geological map of the region it can be seen that the Havelock deposit is located near a significant inflection of the "ore zone" serpentinite body. Although no similar flexure is apparent in the Msauli mine area it is evident that the two major asbestos deposits are situated symmetrically about a conjugate-type regional fold structure having, as its core, a highly disturbed zone of Fig Tree and Moodies Group sedimentary rocks.

Details of the Havelock asbestos deposit have been made available by van Biljon (1959, 1964), Pretorius (1961), and Mackenzie (1965), all of whom reported signs of magmatic differentiation, despite the severely altered nature of the rocks in the mine area. They described apple-green serpentinite, derived from original peridotite or dunite (as evidenced by relic olivines), passing into dark-green serpentinite (conceivably derived from pyroxenite), and this, in turn, passing into a hanging-wall "sill" of diabasic composition. A similar sequence of rock types is encountered in the Msauli mine where original olivines and pyroxenes have been noted (Viljoen and Viljoen, 1969b).

A schematic section across the Havelock ultramafic body is shown in Figure 6. A reinterpretation of the geology suggests that the ultramafic body may, before alteration, have consisted of a cyclically layered complex not unlike those described elsewhere in the Barberton Mountain Land. The steatized serpentinite and the dark-green serpentinite may originally have been dunite-peridotite and orthopyroxenite respectively, while the light-green serpentinites, in which the economic fiber is developed, would most certainly have been dunitic in composition. It is, furthermore, conceivable that the hanging-wall "diabase sill" could represent a metagabbroic terminal phase of the differentiated body.

Geochemical analyses of the Havelock serpentinites and chrysotile fiber are listed in Table 2. A significant variation is evident between the dark-green and the light-green serpentinite varieties supporting the contention that the former was probably derived from an Mg-rich orthopyroxenite. The better quality chrysotile fiber shows a higher than average Fe_2O_3 content (3.67%), the latter exceeding the 2.9 percent upper limit necessary for chrysotile stability suggested by Nagy and Faust (1965).

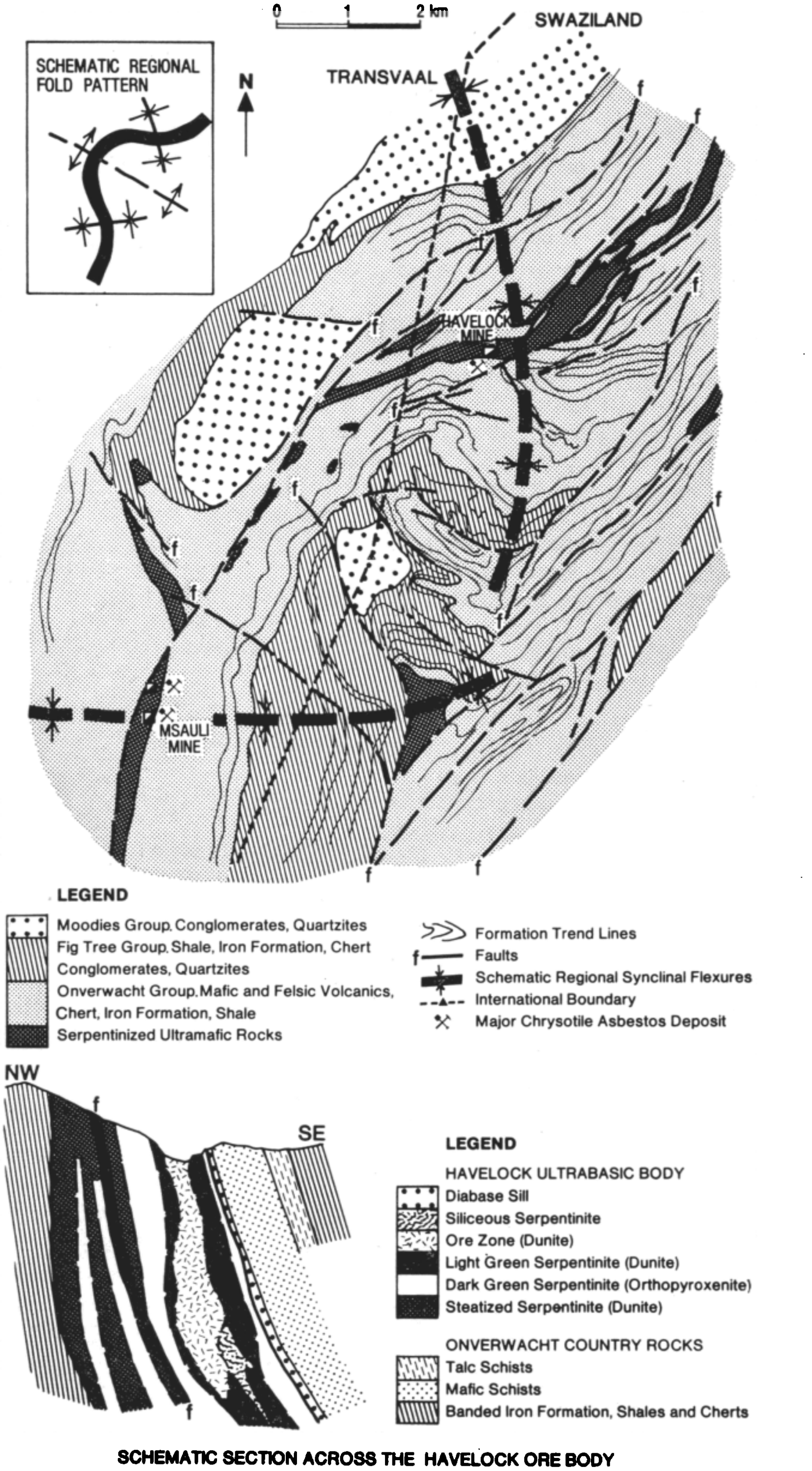

FIG. 6. Map showing the regional geological and structural setting of the Havelock and Msauli asbestos mines in the vicinity of the Transvaal-Swaziland border. (Adapted from Hunter and Jones, 1969.) Also illustrated is a schematic section across the Havelock ultramafic body. (Modified after Mackenzie, 1965.)

The Kalkkloof ultramafic body

The Kalkkloof ultramafic body is situated approximately 60 km southwest of Barberton and 20 km west of the Stolzburg ultramafic body described earlier (Fig. 1). Geologically it is similar to the Kaapsehoop and Stolzburg ultramafic complexes being located in the lower division of the Onverwacht Group and associated with mafic and ultramafic lavas and quartz sericite schists.

The rocks of the complex consist predominantly of north-northeast-trending serpentinized dunites and orthopyroxenites with subordinate metagabbroic phases. The formations dip 45° to 60° NW and the asbestos mineralization, as was the case in the Kaapsehoop body, occurs in the form of parallel seams (ribbon fiber) in the light-green serpentinite (dunite) at the contacts with the dark-green variety (orthopyroxenite). Descriptions of the Kalkkloof asbestos deposits are given by Hall (1930) and van Biljon (1964). At least five fiber-bearing zones occur in the mine and it is evident that the ultramafic body is comprised of several alternating cycles of cumulate olivine-rich and orthopyroxene-rich layers. Several cross-cutting diabase dikes occur in the mine area and van Biljon (1964) indicated that fiber development is confined almost entirely to the western side of a prominent fault-dike which cuts the body in a north-south direction. He further suggested that a genetic relationship exists between the faulting and asbestos fiber formation.

The Rosentuin ultramafic body

On the southern side of the Barberton Mountain Land is a layered sill-like ultramafic complex referred to by Viljoen and Viljoen (1969b) as the Rosentuin ultramafic body. Situated within the Hooggenoeg Formation of the upper part of the Onverwacht Group (and therefore grouped with the Mafic-to-Felsic Unit), the Rosentuin body, from base to top, consists of the following rock types: At the base, in contact with a banded chert layer, is an olivine peridotite or dunite unit followed upward by wehrlite (olivine plus diallage), lherzolite (olivine plus diallage plus orthopyroxene), and websterite (ortho- and clinopyroxene) layers. Overlying this succession is a carbonated agglomeratic breccia, followed by a banded chert.

The Rosentuin body is structurally little disturbed, there being only some minor faulting and dike intrusion. Asbestos mineralization is not abundant but is found along the entire length of the 16-km-long body, occurring only in the basal dunite-peridotite layer. The Rosentuin mine is located where faulting has disturbed the layered sequence. Mineralization, according to Viljoen and Viljoen (1969b), also appears to be partly controlled by the contact of the "ore zone" serpentinite with a resistant peridotite layer within the body. The fiber produced from this area was, however, of a semi-brittle, poorer quality.

The Muldersdrif Ultramafic Complex

Situated approximately 25 km northwest of Johannesburg, in an Archean greenstone remnant on the western extremity of the Johannesburg granite dome, is the Muldersdrif ultramafic body. Although extrusive ultramafics and basaltic pillow lavas occur in the area, the Muldersdrif body is separated from these assemblages by intrusive granites and forms a composite mass in which the formations trend predominantly in an east-west direction (Fig. 7). Correlated with the Lower Ultramafic Unit, the differentiated ultramafic complex comprises an unknown number of cycles, each consisting of a variety of ultramafic rock types and terminating with a medium- to fine-grained metagabbroic member (Anhaeusser, 1972b).

The ultramafic rocks are altered everywhere to serpentinites but evidence is available suggesting the former presence of dunites, peridotites, harzburgites, wehrlites, and Mg-rich pyroxenites. A limited amount of geochemical data relating to rocks in the complex is provided in Table 2.

Detailed mapping of the layered complex showed that the region has been subjected to several superimposed fold deformations, the latter resulting in the development of a complex outcrop pattern (Fig. 7). The chrysotile asbestos development appears to have been largely dependent on the style of deformation and on the composition of the deformed host rocks. Almost invariably the asbestos fiber of significance is located in the basal portion of dunite-peridotite zones where these rocks immediately overlie massive, fine-grained, metagabbroic terminal phases of a preceding differentiated cycle. Competency contrasts and differential movement at these contacts are clearly responsible for fiber growth.

Three small asbestos deposits (Gelden, Scott, and West Rand asbestos mines) were exploited mainly before World War II and yielded a relatively poor quality fiber. Numerous prospects occur in the region but no subsequent mining has been attempted.

Asbestos Occurrences in Rhodesia

The Mashaba Igneous Complex

The Mashaba complex occurs at the western end of the Fort Victoria greenstone belt, in the southern part of Rhodesia (Fig. 1). It forms a layered, predominantly ultramafic, intrusion which can be divided into sheeted and dike portions. The sheeted portion consists of four recognizable units, believed by Wilson (1968a, b) to represent separate injections of

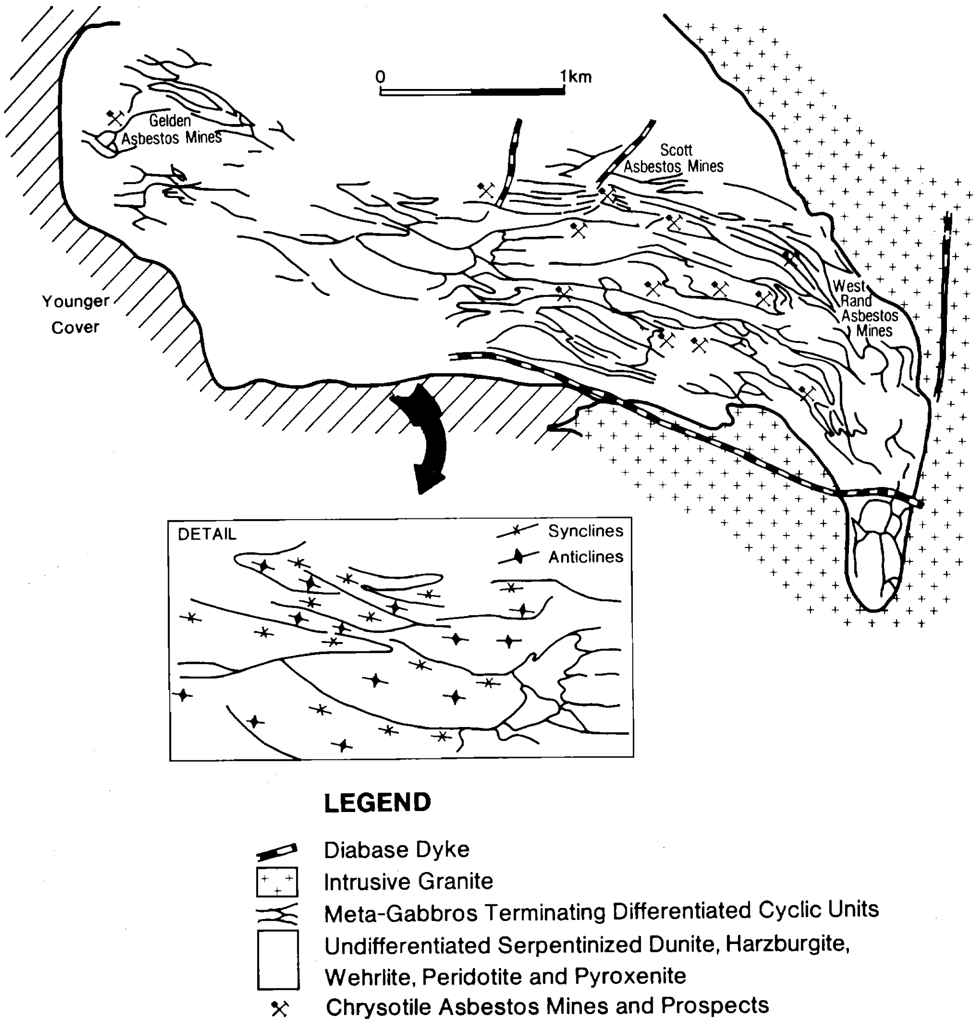

FIG. 7. Map of the complexly folded Muldersdrif ultramafic body showing the distribution of asbestos mineralization at serpentinite-metagabbro contacts.

magma emplaced one beneath the other, with the oldest and most ultramafic pulse at the top. The dike portion, considered to be the feeder of the intrusion, has the form of a discontinuous ring dike.

According to Wilson (1968a), the Mashaba Igneous Complex (Fig. 8) appears to have been emplaced after the main phase of folding which affected the rocks of the Fort Victoria schist belt. It was, however, intruded before the emplacement of a late Archean granite which Wilson (1968b) has suggested represents a late-tectonic granite of post-Shamvaian age (~2,600–2,900 m.y. old).

The successive magma heaves of the complex underwent differentiation in situ and were consolidated (but not cold) before the intrusion of the next magma pulse. The topmost, highly ultramafic inflow crystallized to form a thick basal layer of chromite, followed upward by further rhythmic layers of chromite and dunite (now serpentinized). This pulse was of small lateral extent but provided the high-grade chromite mined in the Prince mine area. The second, and largest, pulse yielded more dunite-peridotite and small pockets of pyroxenite and gabbroic rocks in the topmost portion of the layer. The third and fourth pulses were smaller in volume and progressively poorer in olivine than the earlier cycles. Each segregated into mafic and ultramafic fractions, with the fourth pulse, nearest to the feeder, producing a thick pyroxenite layer grading upward into a further thick layer of gabbroic rocks. Finally, mafic dikes were emplaced. In Table 3, chemical analyses of some of the principal rock types encountered in the Mashaba complex are listed for comparison with other ultramafic bodies described in this paper.

The entire sequence was subsequently deformed by the intrusion of granite and the complex was subjected to compression which resulted in cross folding of the sheeted portion. Thrusting took place along the base of the sheet. In the southeast the complex attains its greatest structural complexity, being intricately folded and faulted on a grand scale (Fig. 8).

An important result of the deformation of the Mashaba Igneous Complex is the development of chrysotile asbestos fiber on an economic scale. Figure 8 shows the distribution of asbestos mines and prospects in the ultramafic complex in relation to folding, thrusting, and faulting. Greatest emphasis has, in the past, been placed on the fracture systems being the dominant controlling factors in the formation of asbestos fiber deposits (Wilson, 1968a, b; Laubscher, 1968). While this control is undoubtedly of great importance, further regard should also be taken of the regional and local fold patterns in the area as major additional contributory factors in fiber localization. As can be seen in Figure 8, which is a simplified sketch map (modified after Wilson, 1968b), the majority of noteworthy asbestos showings are located in fold hinges or on fold limbs. It may therefore be unjustified to discount or minimize the role of folding as a genetic control in fiber growth.

In the Mashaba district approximately 75 percent of all the absestos has been produced from the Gath's and King mines. Two types of fiber body can be distinguished in the deposits of the area—banded lodes (ribbon fiber) and stockworks. Banded lodes occur in the Gath's mine, whereas interlacing fiber networks, or stockworks, occur in the King mine.

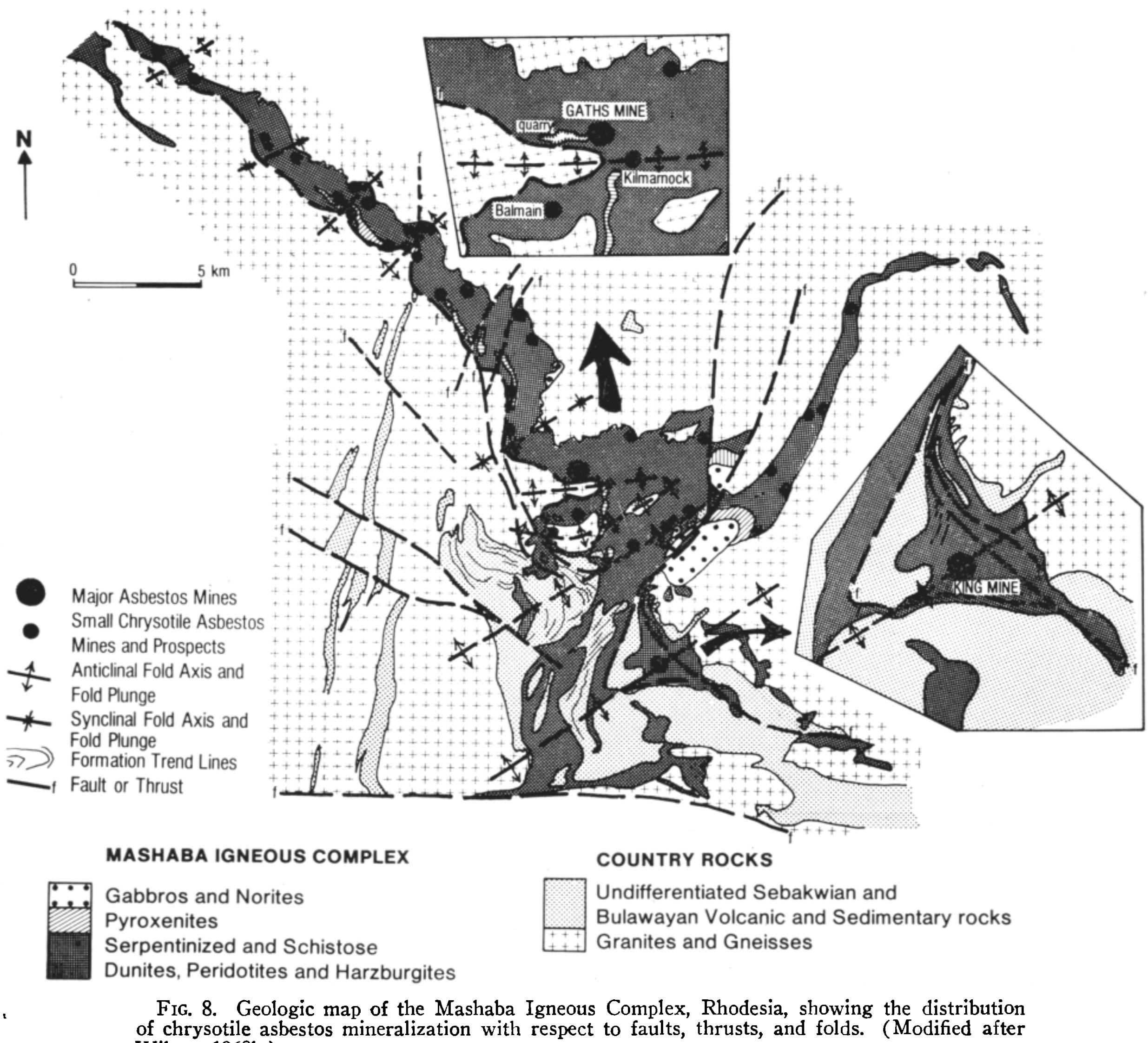

FIG. 8. Geologic map of the Mashaba Igneous Complex, Rhodesia, showing the distribution of chrysotile asbestos mineralization with respect to faults, thrusts, and folds. (Modified after Wilson, 1968b.)

TABLE 3. Chemical Analyses: Archean Layered Ultramafic Complexes; Chrysotile Asbestos; the Great Dyke, Rhodesia and Serpentinized Dolomite, Transvaal, South Africa

	MASHABA IGNEOUS COMPLEX, RHODESIA				SHABANI ULTRABASIC BODY, RHODESIA					GREAT DYKE, RHODESIA			SERPENTINIZED DOLOMITE - TRANSVAAL SUPERGROUP
	1	2	3	4	5	6	7	8	9	10	11	12	13
	BR 28	63/345	63/344	63/309	G. 82	G. 42	G. 43			P569	G156	G133	V168
SiO_2	41.42	51.15	57.23	48.12	37.11	40.90	39.62	41.70	39.00	39.12	37.03	42.15	28.22
Al_2O_3	1.52	1.20	11.70	15.38	2.17	1.66	3.66	0.74	1.98	1.77	1.52	0.58	9.98
Fe_2O_3	4.16	3.42	1.27	1.96	4.74	2.02	4.55	2.39	6.88	0.22	1.16	1.45	1.14
FeO	5.65	6.77	6.89	10.88	4.06	0.69	2.36	-	-	10.21	1.69	0.96	0.36
MgO	39.77	34.00	8.68	6.87	43.53	39.92	35.66	39.72	37.87	45.88	42.73	40.76	32.00
CaO	1.23	0.93	8.12	11.21	Nil	Nil	Nil	1.78	0.73	0.96	-	-	8.58
Na_2O	Nil	0.11	1.91	1.85	0.42	-	-	-	-	0.09	0.11	-	0.06
K_2O	0.15	0.02	1.38	0.24	0.23	-	-	-	-	0.16	0.23	-	0.08
TiO_2	0.10	0.04	0.33	1.30	Nil	tr	-	-	-	tr	-	-	0.52
P_2O_5	tr	0.10	0.07	0.15	tr	-	-	-	-	-	0.03	-	0.05
MnO	0.19	0.21	0.15	Nil	0.16	0.07	tr	-	-	0.16	0.05	0.10	0.43
CO_2	0.29	0.09	0.09	tr	0.78	0.04	0.08	-	0.02	-	-	-	6.84
H_2O	5.03	2.02	2.66	1.85	6.44	14.83	14.22	13.65	13.34	0.18	13.44	14.03	11.68
Total	99.51	100.01	100.33	99.99	100.00	100.13	100.15	99.98	99.82	98.75	97.99	100.10	100.24

1. Harzburgite.
2. Olivine pyroxenite.
3. Metagabbro.
4. Metadolerite.
5. Dunite (partly serpentinized), Shabanie Mine.
6. Silky fiber. Nil Desperandum Section, Shabani Area.
7. Brittle fiber. Nil Desperandum Section, Shabani Area.
8. Silky fiber, Birthday Section, Shabani Area.
9. Serpentinite adjacent to silky fiber, Birthday Section, Shabanie Mine.
10. Dunite (Wedza Complex).
11. Serpentinite, Ethel Mine (Hartley Complex).
12. Chrysotile asbestos fiber, Ethel Mine.
13. Brown serpentinized dolomite associated with good quality fiber. Congo-Vaal Asbestos Mine, Carolina District, Eastern Transvaal.

Analyses : 1-4 (Wilson, 1968b); 5-7 (Keep, 1929); 8-9 (Laubscher, 1964); 10-12 (Worst, 1960); 13 (van Biljon, 1959).

The Shabani ultramafic body

The Shabani ultramafic body is located on the northwest margin of the Belingwe greenstone belt, east of the Great Dyke (Fig. 1). The Shabanie mine is the largest occurrence of chrysotile fiber in Africa, producing approximately 60 percent of Rhodesia's asbestos, with the Mashaba mines contributing most of the remainder (~35 per cent).

The geology of the Shabani asbestos deposits has been well documented, first by Keep (1929) and later, in greater detail, by Laubscher (1963, 1964, 1968).

A number of disconnected orebodies are located in the central footwall dunite of a lenticular ultramafic sill which, according to Laubscher (1964), has intruded into the Archean gneisses along the northeast margin of the Belingwe schist belt. The formations in the latter greenstone belt are correlated with the Bulawayan Group (Mafic-to-Felsic Unit). No reliable age determinations are available for the rocks in the area but Laubscher (1968) considers the Shabani Ultramafic Complex to be a post-Bulawayan intrusive. In a review of the available evidence in the region Morris (1968) concluded, however, that the ultrabasic bodies were most probably emplaced during a late stage in the development of the Sebakwian succession, a view that is supported by the present writer. Wilson (1973) equates many of the ultrabasic complexes in the southern regions of Rhodesia with events contemporaneous with the emplacement of the Mashaba Igneous Complex which he regards as being of post-Shamvaian age (~2.6–2.9 b.y. old).

Although uncertainties may still hinge around the age of the various Archean successions in the Shabani and Mashaba areas there seems little doubt as to the nature of the geological assemblage which acts as host to the important asbestos ore deposits. Laubscher (1964) indicated that the Shabani ultramafic body has a strike length (NW-SE) of just over 14 km and a thickness of approximately 1.5 km (Fig. 9).

The ultramafic mass was intruded as a sill which segregated from its base upward into dunite, peridotite, pyroxenite, and gabbro. Harzburgite and pyroxenite were also developed in some localities both to the west and east of Shabanie Township.

From base to top Laubscher (1964) recognized the following rock types, the distribution of which can be seen in Figure 9. 1. Footwall talc-carbonate rocks—composed mainly of talc-magnesite schists and graphite schists in shear zones, talc-magnesite rocks, and magnesite rocks. The zone represents altered serpentinized dunites. 2. Brittle fiber zone—

12 to 180 m in thickness representing a transition zone in the dunite of decreasing CO_2 metasomatism. Brittle fiber (see chemical analyses, Table 3), which results from the replacement of chrysotile layers by magnesite and talc, gives way gradationally to silky fiber after first passing through a zone of harsh fiber. 3. Silky fiber bodies—representing the good-quality fiber in the various orebodies strung out along the central footwall dunite of the Shabani complex. The orebodies are commonly separated by zones of talc in CO_2-metasomatized fractures and faults. 4. Partly serpentinized dunite—with a thickess of approximately 750 m, forming the bulk of the ultramafic mass. Remnant olivines are seen in places. Analyses of partly serpentinized dunite and silky fiber from the ore zone are listed in Table 3. 5. Peridotites—occurring as an indefinite zone in the upper portion of the main mass and in the northern outliers (Fig. 9). 6. Hanging-wall talc rock—found in the main mass at the contact of the peridotite and actinolite rock (uralitized pyroxenites). 7. Harzburgites—the latter not developed in the main mass but occurring in the northern outliers. The rocks contain olivine and more than 20 percent orthopyroxene. 8. Pyroxenites—found as lenticular bodies in the central and western hanging walls of the main mass (Fig. 9) and consisting of Mg-rich orthopyroxene and subordinate clinopyroxene. 9. Actinolite rocks—comprised of uralitized pyroxenites containing minor amounts of calcic plagioclase and zoisite. 10. Actinolite-feldspar rock—representing altered gabbros and found in the central and western hanging-wall-area of the main body.

The rocks of the ultramafic complex were subjected to deformation, presumably associated with the emplacement of granites in the area. Extensive fracturing of the footwall dunite occurred in a direction subparallel to the gneiss contact, with the fracture spacing increasing away from the contact. At the same time, the ultramafic body was folded into shallow anticlines and synclines, followed by further wrench movements as well as extensive sympathetic fracturing, slipping, and shearing. Aplitic and pegmatitic granite intrusions accompanied the disturbances and, according to Laubscher (1968), assisted in distributing hydrothermal solutions along faults

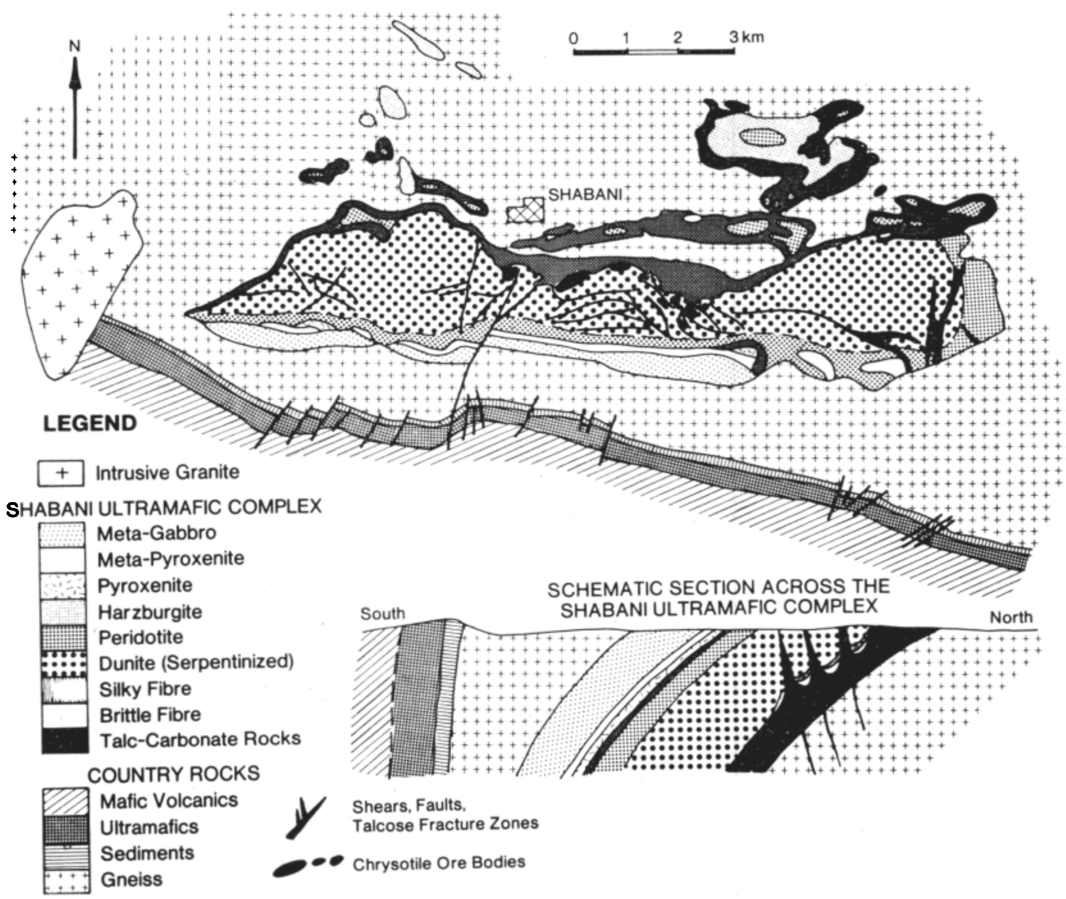

FIG. 9. Map of the Shabani Ultramafic Complex, Rhodesia, showing the distribution of the main chrysotile asbestos orebodies. (Adapted from Laubscher, 1964.)

and fissures resulting in the development of carbonated serpentinites and the talc-carbonate zones separating the chrysotile orebodies.

The Shabani ultramafic body demonstrates a single stage, or cycle, of segregation and appears to have undergone a greater degree of magmatic differentiation than most other ultramafic bodies in southern Africa. This has resulted in a major development of dunite at the base of the complex, the latter possessing the requisite chemical and textural properties necessary for the subsequent development of chrysotile fiber on a major scale.

The Filabusi ultramafic complexes

Chrysotile fiber-bearing serpentinite bodies occur in the Filabusi greenstone belt, which is located in the southern part of Rhodesia, west of the Great Dyke (Fig. 1). Descriptions of the regional geology of the Filabusi area have been given by Ferguson (1934), but few details are available of the ultramafic bodies or of the asbestos occurrences in them. The ultramafic bodies appear to form part of the stratigraphy of the greenstone belt in much the same manner as the complexes in the Barberton greenstone belt. They probably represent concordant sills in a succession of mafic volcanics similar to those of the Lower Ultramafic Unit.

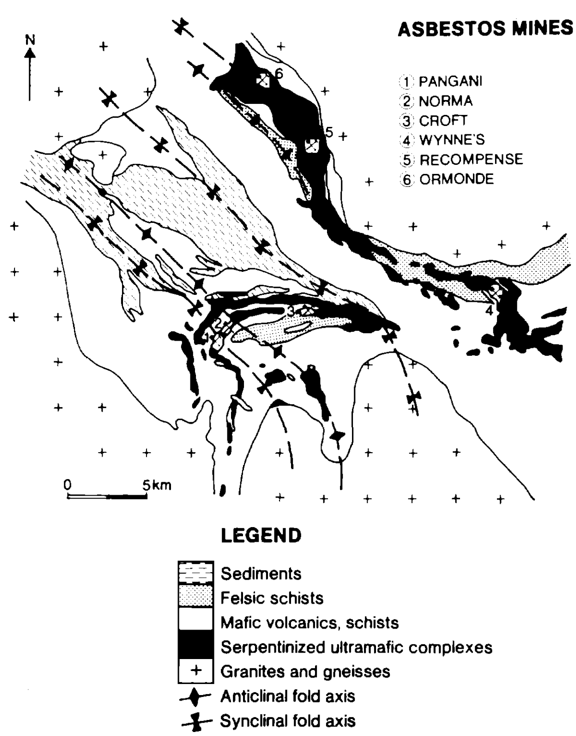

FIG. 10. Geologic map of portion of the Filabusi greenstone belt, Rhodesia, showing the distribution of asbestos deposits in the folded ultramafic bodies in the region. (Modified after Ferguson, 1934.)

The ultramafic bodies consist mainly of serpentinized dunite-peridotite and altered pyroxenites and gabbroic rocks, the successions being similar to the layered complexes described earlier. The distribution of the ultramafic bodies, as well as the asbestos mines in the area, is shown in Figure 10. It is evident that the economic fiber occurrences are once again situated either in, or adjacent to, fold hinges or on the limbs of folds. The Pangani asbestos mine, which is directly in the core of the main fold in the area, is also the largest deposit in the Filabusi region.

Apart from the chrysotile asbestos, the controls of which are clearly related to rock composition and structure, there are abundant seams of magnesite common to some areas. Opaline silica and magnetite are also encountered in the ultramafic rocks.

Asbestos in the Great Dyke, Rhodesia

The Great Dyke of Rhodesia, which is 2,532 ± 89 m.y. old (Davies et al., 1969), is an elongate mass of mafic and ultramafic rocks extending for nearly 500 km across the Rhodesian Craton. Its maximum width is about 11 km, and it is not a true dike but the remains of four lopolithic intrusions arranged in a straight line and downfaulted into a graben-like structure (Worst, 1960).

The rocks are igneous cumulates, with ultramafic types predominant. All four complexes are similar in structure, and component rock types show marked layered sequences indicative of differentiation and crystallization in a stable environment.

The Great Dyke, apart from its vast reserves of high-grade metallurgical chrome, is host to important platinum mineralization. In addition, small quantities of chrysotile asbestos are found mainly in disturbed areas in the vicinity of faults which have displaced the dike laterally.

The only producing mine on the Great Dyke is the Ethel asbestos mine, situated near the northern end of the dike (Fig. 1). The mine is located on the southern side of a fault which displaces the dike more than 300 m (Fig. 11). In the mine the fiber occurs in near-vertical seams concentrated in three parallel, east-west-trending zones. Each zone is separated by relatively barren serpentinite. No asbestos is developed in the fault plane but instead occurs some distance south of the actual dislocation, where conditions were presumably more favorable for fiber formation.

The country rock of the asbestos was originally either harzburgite or dunite. The fiber measures between 1 and 25 mm in length and is of particularly fine quality. It is, however, intimately admixed with brucite which provides separation problems. Chemical analyses of the Great Dyke asbestos fiber, and

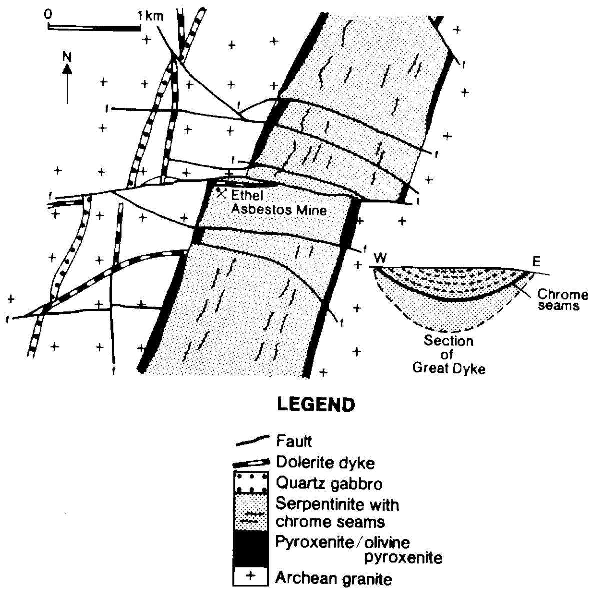

FIG. 11. Asbestos mineralization associated with faulting in the Great Dyke, Rhodesia. (Adapted from Worst, 1960.)

host rock serpentinite and dunite, are listed in Table 3. Compared with asbestos fiber analyses discussed previously, the Ethel fiber has particularly low percentages of Al_2O_3 and Fe_2O3 but is slightly more SiO_2 enriched.

Asbestos in the Serpentinized Dolomites of the Transvaal Supergroup

Chrysotile asbestos deposits, derived by thermal alteration of dolomite, are known from around the Transvaal Basin, where dikes and sills have altered the Malmani Dolomite. The principal deposits, which have been described in detail by Hall (1930) and van Biljon (1959, 1964), are located in the eastern Transvaal, especially in the escarpment regions to the west of the Barberton Mountain Land (Fig. 1). Here, Bushveld-age sills ($\sim$1,950 m.y. old) intrusive into the dolomite are particularly abundant. The sills commonly produce a metamorphosed assemblage extending for a meter or more above the upper chilled contacts. In these alteration zones, the dolomite is partly dedolomitized to a calcitic rock which occurs along with serpentine and talc. The serpentine is often clearly pseudomorphous after chert, frequently displaying delicate depositional structures such as ripple marks, algal laminations, and stromatolites (Button, 1974). Within the serpentine, an analysis of which is provided in Table 3, fibers of chrysotile asbestos are developed. According to van Biljon (1964), fiber formation is related to minor deformations in the dolomite. He is of the opinion that the fiber-producing reaction can occur at temperatures below 500°C.

The controls on the mineralization involve:

(1) A source of both Mg and Si (the former is supplied by dolomite, the latter by interbedded chert).

(2) A source of H_2O (this is supplied by volatiles streaming off the cooling sill).

(3) A source of heat to drive the thermal reaction (supplied by the sill itself).

The first control is illustrated by the fact that, adjacent to sills intrusive into chert-free dolomite, no fiber is developed; the second by the fact that the fiber is invariably found above the sill, the expected position of volatiles (Button, 1974).

In Figure 12, a schematic section of the eastern Transvaal escarpment region is given and the distribution of asbestos mineralization relative to the dikes and sills in the dolomites is illustrated.

Discussion

It is evident, from foregoing descriptions of the more important chrysotile asbestos occurrences in southern Africa, that there are a number of important unifying features common to all the deposits, the exception being the chrysotile orebodies associated with the dolomitic rocks.

Undoubtedly, the prime requisite for the development of chrysotile fiber centers about the suitability of the host rock starting material. Chrysotile asbestos is only found in serpentinite and, as the latter forms by the alteration of a wide variety of rock types (e.g., dunites, peridotites, harzburgites, wehrlites, lherzolites, picrites, pyroxenites, and dolomites), it is important to define more specifically the variety most likely to prove of significance in any search for the mineral.

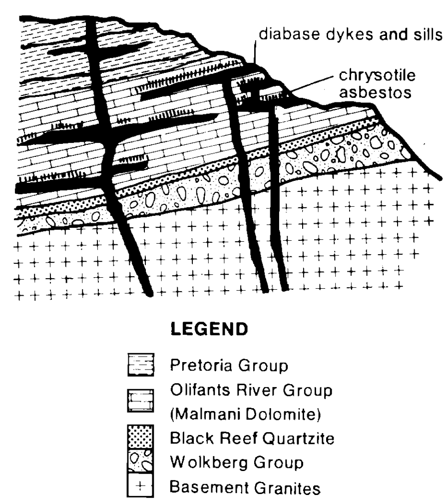

FIG. 12. Schematic section illustrating the distribution of chrysotile asbestos mineralization above diabase sills intruded into dolomitic rocks of the Transvaal Supergroup.

TABLE 4. Comparison of the Bulk Chemistry of Some Layered Ultramafic Bodies in the Barberton Mountain Land, with the Average Chemistry of Extrusive Peridotitic Komatiite

	1	2	3	4	5
SiO_2	46.64	46.80	46.58	50.13	45.94
Al_2O_3	4.01	2.56	3.95	3.24	2.98
Fe_2O_3	3.30	3.74	2.65	3.32	6.53
FeO	5.82	6.29	5.51	4.64	4.80
MgO	32.50	35.43	28.34	32.43	33.79
CaO	4.76	2.50	3.69	5.25	4.73
Na_2O	0.20	0.51	0.62	0.67	0.15
K_2O	0.04	0.06	0.04	0.03	0.03

1. Ship Hill ultramafic body (Viljoen and Viljoen, 1969c).
2. Koedoe ultramafic body (Viljoen and Viljoen, 1969c).
3. Stolzburg ultramafic body (provisional estimate only based on ultramafic/mafic ratio of 3:1).
4. Handsup-Mundt's Concession ultramafic body (Anhaeusser, 1969).
5. Average peridotitic komatiite lava, Komati Formation, Barberton greenstone belt (Viljoen and Viljoen, 1969c).

It is now firmly established that extrusive ultramafic rock types do exist. The most convincing evidence supporting this has come from the Archean greenstone belts (Wiles, 1957; Viljoen and Viljoen, 1969d; Nesbitt, 1971), but submarine ultramafic lava outpourings have been reported from younger environments (Bailley and McCallien, 1953; Gass, 1958; Maxwell and Azzaroli, 1963). In their present situation, most serpentinized ultramafic rocks, no matter what their age, are found in orogenically disturbed areas. Under tectonic influences, rocks of this nature tend to behave plastically and readily distort, or "flow", into massive, often discontinuous, pods and lenselike bodies. The latter are usually totally serpentinized, and it is often difficult to visualize such rocks as having formed part of what may have been an essentially extrusive layered sequence. Because of the structural disturbances suffered by these rocks, chrysotile asbestos fiber may be developed in them and much effort could be spent in establishing sufficient ore to warrant exploitation.

The descriptions of the various chrysotile deposits in southern Africa leave little doubt, however, that the most favorable ultramafic host rocks for chrysotile fiber are the olivine or olivine-orthopyroxene cumulate rocks invariably found at, or near the base of, intrusive layered differentiated complexes. Where fractional crystallization of the primary magma was most efficient, cumulus minerals appear to have settled out rapidly, causing monomineralic phases to develop. Coupled with this, the individual minerals, forming a particular cumulate layer, appear to have reached a high degree of purity, the olivines and orthopyroxenes, for example, being particularly magnesium-enriched fosterites and bronzites or enstatites. Added to this, little or no intercumulus liquid was able to accumulate.

The nature of the parental magmas, from which most of the southern African layered ultramafic complexes were derived, also played a dominant role in determining their character and potential as hosts for fiber development. These magmas, it has been established (Anhaeusser, 1969; Viljoen and Viljoen, 1969c), were peridotitic in composition in contrast to the basaltic (tholeiitic) magmas from which the large differentiated, gabbroic layered intrusions like Stillwater, the Bushveld, Skaergaard, and others, were formed. In Table 4, a comparison is drawn between the bulk composition of some of the Archean ultramafic complexes in the Barberton greenstone belt and the extrusive peridotitic komatiites found in the same region.

As chrysotile asbestos is a stress-controlled mineral, it follows that, without the requisite structural deformation, even the most ideal dunite or peridotite host rock will be unsuited for the development of fiber. Systematic structural studies in many asbestos deposits throughout the world have shown that cross-fiber asbestos seams require tensional conditions for fiber growth, whereas slip fibers are localized in planes along which shearing has taken place (Hall, 1930; Cooke, 1937; Riordon, 1955; Laubscher, 1964, 1968; van Biljon, 1964). Emphasis has largely been placed on faulting, of one sort or another, as constituting the most important fiber growth mechanism. Laubscher (1968), for example, summarized the main features of structural control as being:

(1) The formation of fractures in which stress-controlled dilation seams can form and from which serpentinization can take place;

(2) The development of thrust faults, wrench faults, and shear zones, the latter acting as channelways for hydrothermal solutions essential to the serpentinization of the potential fiber host rocks. Associated with the faulting would be areas where stress-controlled dilation seams could develop. Significantly, it is stated, fiber is best developed in those areas having the simplest structural pattern;

(3) Where wrench faulting is dominant, slip fiber is localized in the fault zone or sympathetic structures;

(4) The presence of structures which create the correct stress environment, allowing serpentine minerals to recrystallize to form fiber seams.

Whereas faulting undoubtedly played a prominent role as a fiber growth mechanism, it is partly the purpose of this paper to draw attention to the significant role that folding plays in the localization of chrysotile ore deposits. Expressed differently, folding appears, in many instances, to be the dominant regional controlling factor for asbestos development, whereas faulting and fracturing provides the more localized control governing fiber growth and fiber density. In effect, the various fiber-controlling factors cannot be separated as they are intimately related, the one being dependent on the other.

In conclusion, it is suggested that in any search for chrysotile asbestos, and more specifically in Archean terrains, exploration philosophy should take cognizance of the regional fold patterns, particularly where these may involved layered differentiated ultramafic complexes.

Economic Geology Research Unit
University of the Witwatersrand
Johannesburg, 2001, South Africa

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