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THE GEOLOGICAL SETTING OF CHRYSOTILE ASBESTOS OCCURRENCES IN SOUTHERN AFRICA

by

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ABSTRACT

In this contribution the principal chrysotile asbestos occurrences in Zimbabwe, South Africa, and Swaziland are described, emphasis being placed on the regional geological settings and host rock stratigraphy of the mineralized areas. The paper also serves to introduce the following five papers in this volume that describe a selection of chrysotile asbestos deposits in the regions mentioned.

All the more important asbestos ore deposits in Southern Africa are Archaean in age (∼2 500–3 500 Ma 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 komatiites and komatiitic basalts, 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 Archaean 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 fibre generally occurs in dunites, peridotites, or harzburgites.

All the Southern African Archaean layered complexes appear to have been derived from magmas 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. The Great Dyke in Zimbabwe, unlike the others, also acts as host to small chrysotile deposits developed in serpentinized dunite or harzburgite.

In addition to the asbestos mineralization found in the layered complexes, subordinate deposits, occurring in serpentinized dolomitic rocks associated with the ∼2 200 Ma old Transvaal Sequence, are briefly described.

Whereas faulting and fracturing is generally acknowledged as being largely responsible for the local development of asbestos fibre, 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.

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I. INTRODUCTION

Southern Africa ranks third in the world, after Canada and the USSR, as a producer of chrysotile asbestos. Almost the entire Southern African production has emanated from Archaean layered ultramafic complexes, most of which are associated with the ancient greenstone belts on the Rhodesian and Kaapvaal cratons. This is in marked contrast to the Candian and USSR production which stems almost totally from late Precambrian to Palaeozoic "alpine-type" peridotite and pyroxenite intrusives associated with the eugeosynclinal sediments of the Appalachian and Ural fold belts (Anhaeusser, 1976, 1985). In addition to the chrysotile asbestos deposits associated with layered ultramafic complexes, like those recorded in the greenstone belts of Zimbabwe (Keep, 1929; Ferguson, 1934; Laubscher, 1964, 1968, 1985a, b; Wilson, 1968a, b), South Africa (Hall, 1930; Visser *et al.*, 1956; Van Biljon, 1964; Anhaeusser, 1969, 1972, 1974, 1976, 1978, 1985; Viljoen and Viljoen, 1970; Groeneveld, 1973; Wuth, 1980; Büttner, 1983; Menell *et al.*, 1985; Voight *et al.*, 1985), and Swaziland (Urie, 1961; Van Biljon, 1964; Barton, 1982, 1985), there are smaller deposits associated with ultramafic rocks of the Great Dyke in Zimbabwe (Worst, 1960) and with serpentinized dolomites of the Transvaal Sequence on the Kaapvaal Craton (Button, 1974; Anhaeusser, 1974, 1976) (see Fig. 1).

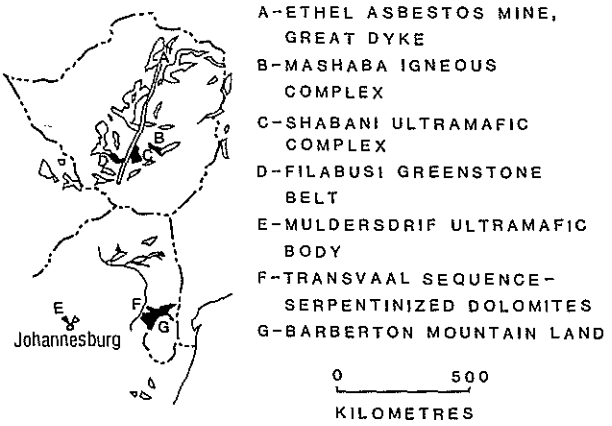

Figure 1

Locality map showing the distribution of the principal chrysotile asbestos producing regions on the Kaapvaal and Rhodesian cratons.

Five papers in this volume provide details of some of these chrysotile asbestos occurrences. Laubscher (1985a) has described the principal deposits in the Zvishavane (Shabani) and Mashava (Mashaba) areas of Zimbabwe, and Barton (1985) has contributed a description of the Havelock asbestos mine in the Swaziland sector of the Barberton greenstone belt. Three other deposits situated in the Barberton Mountain Land, and which are outlined in the volume, include the Msauli Mine in KaNgwane (Voight *et al.*, 1985), the New Amianthus deposit near Kaapsehoop (Laubscher, 1985b), and the Kalkkloof asbestos occurrence near Badplaas (Menell *et al.*, 1985).

This paper, rather than detailing the nature and origin of serpentinites, the mineralogy of serpentine minerals, or chrysotile asbestos fibre growth mechanisms, places emphasis on the host rock stratigraphy and structural setting of the principal ore deposits of this type in Southern Africa. Details of the geochemical characteristics of the layered intrusions, including mineral compositions, are provided by Anhaeusser (1985).

II. GENERAL GEOLOGICAL SETTING OF THE ARCHAEAN ASBESTOS DEPOSITS

Archaean 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* (Viljoen and Viljoen, 1969a) and embraces the pre-Sebakwian and Sebakwian successions of Zimbabwe and assemblages correlated with the lower three formations of the Onverwacht Group of the Barberton Sequence in South Africa and Swaziland (Anhaeusser and Viljoen, 1985).

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* (Viljoen and Viljoen, 1969b). Assemblages falling into this category include rocks of the Bulawayan Group in Zimbabwe 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 Zimbabwe 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 fibre of economic significance is to be found. In addition to the layered complexes, which appear penecontemporaneously within the developing ultramafic and mafic lava successions, there are intrusive ultramafic bodies, like the Mashaba Complex in Zimbabwe, which postdate the greenstone belts, but which are, nevertheless, deformed by the emplacement of Archaean granites.

Studies in the Barberton Mountain Land, both by the writer (Anhaeusser, 1969, 1976, 1985) and Viljoen and Viljoen (1969c, 1970) have provided new information relating to the layered ultramafic complexes, the localities of which are depicted in Fig. 2. These findings supplement the earlier geological descriptions of the chrysotile asbestos occurrences in the area provided by Hall (1921, 1930), Van Biljon (1964), Groeneveld (1973), and Barton (1982).

III. LAYERED ULTRAMAFIC COMPLEXES IN THE BARBERTON MOUNTAIN LAND

A. Regional Geological Setting

The Barberton greenstone belt (Fig. 2) is a north-east-trending, isoclinally folded, metamorphosed volcano-sedimentary succession entirely surrounded by intrusive granitic rocks ranging in composition from tonalite and trondhjemite gneisses and migmatites to granodiorites, adamellites, and granites (*senso stricto*) (Anhaeusser and Robb, 1981). Mafic and ultramafic komatiites and high-Mg basalts predominate in the lower part of the greenstone succession and are overlain sequentially by a dominantly mafic-to-felsic sequence of volcanic flows and pyroclastic rocks cyclically interlayered with cherts (Viljoen and Viljoen, 1969a, b).

The layered ultramafic sills are dominantly in the lower stratigraphic part of the volcanic sequence where they are intimately associated with the extrusive mafic and ultramafic flow units. A small number of intrusive sills are also interlayered with the upper calc-alkaline volcanic

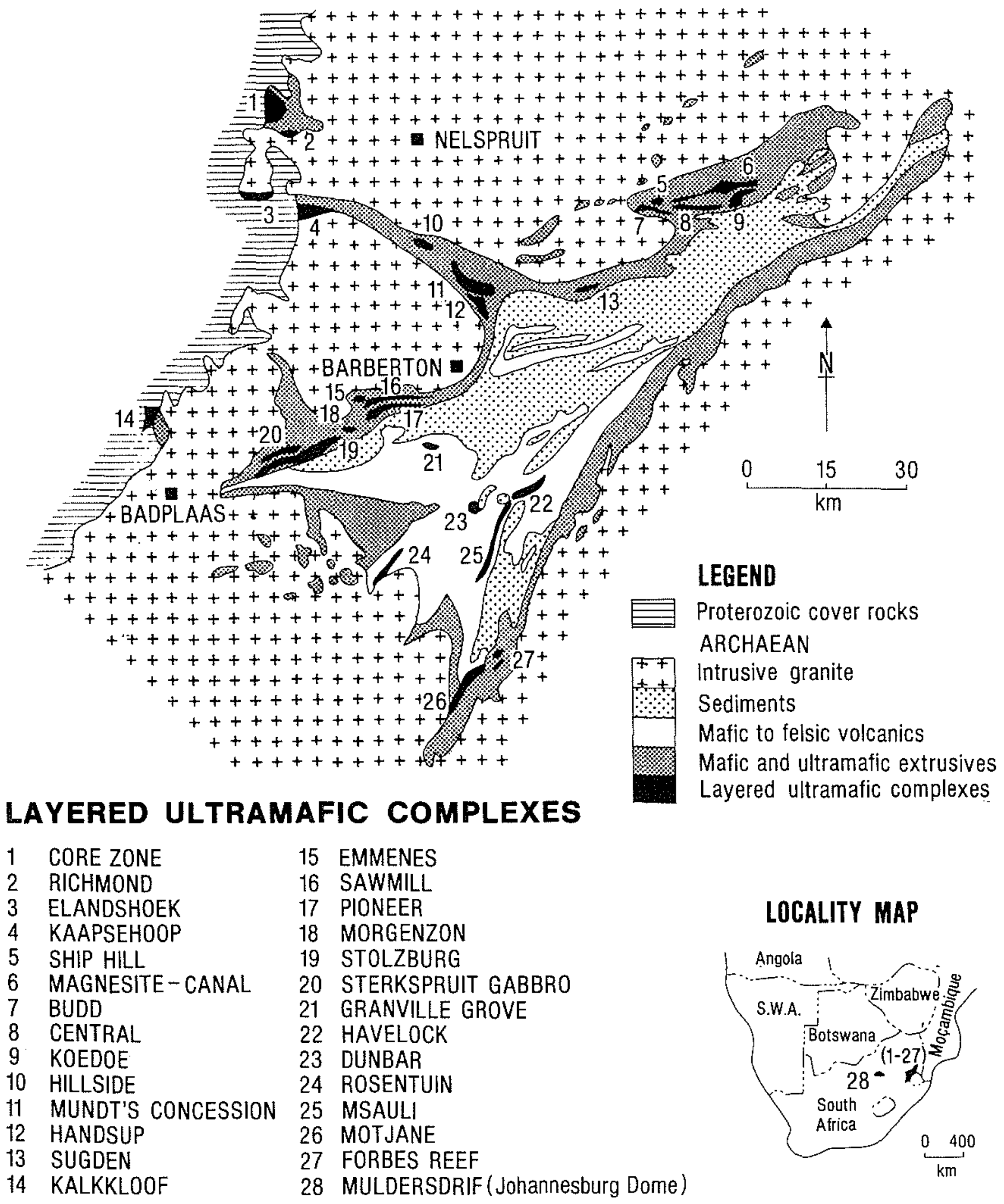

Figure 2

Locality map showing the general geology of the Barberton greenstone belt and the distribution of layered ultramafic complexes (after Anhaeusser, 1985).

sequences, the most important of these being the Havelock and Msauli intrusions which are hosts to two of the largest chrysotile asbestos deposits in Southern Africa (Barton, 1982; Voight *et al.*, 1985). All the layered complexes appear to predate the Fig Tree and Moodies sedimentary sequences, but are locally in direct contact with these rocks due largely to faulting.

The Barberton volcanic sequences have yielded a precise Sm–Nd age of 3 540 ± 30 Ma (Hamilton *et al.*, 1979) and all available evidence suggests that these rocks were subsequently intruded by various granitic rocks ranging in age from approximately 3 450 to 2 500 Ma (Anhaeusser and Robb, 1981; Barton, 1981). Locally, near granitic contacts, the volcanic successions are represented by schists and hornfelses metamorphosed to amphibolite or upper greenschist facies. Elsewhere (and including most of the layered complexes), low-grade metamorphic conditions generally prevailed.

B. General Features of the Layered Complexes

1. Lower Part of Volcanic Sequence

As shown in Fig. 2 most of the layered complexes are associated with assemblages of komatiite and komatiitic basalt and high-Mg basalts or tholeiitic basalts. Some of the layered bodies are clearly sill-like intrusions injected into the volcanic sequences, locally along thin sedimentary layers consisting of banded iron-formation or banded grunerite-chert rocks (Viljoen and Viljoen, 1970). Elsewhere the bodies are massive and broadly concordant with the volcanic units, although intrusive contacts are rarely exposed. Where relationships with the country rocks are transgressive, the discordant contacts are generally faults. In some places the sills bifurcate or occur as multiple sills (Viljoen and Viljoen, 1970; Wuth, 1980).

Although low-grade metamorphism has led to the development of greenschist facies mineral assemblages in most of the complexes the degree of alteration is variable and in places some of the primary minerals are still well preserved. Elsewhere, despite the alteration, the original igneous textures are still evident and only in extremely altered and tectonized zones is it impossible to establish the nature of the original mineralogy.

Most complexes, some of which are up to 1 500 m thick, show marked differentiation and are commonly cyclically layered (Figs. 2–7). However, several coarse-textured, comformable ultramafic pods, now largely serpentinized and steatized, show no indications of either differentiation or layering, whereas others, like the Koedoe, Budd, and Ship Hill intrusions (Figs. 3 and 4) have only one complete, but, nevertheless, well-developed differentiation cycle.

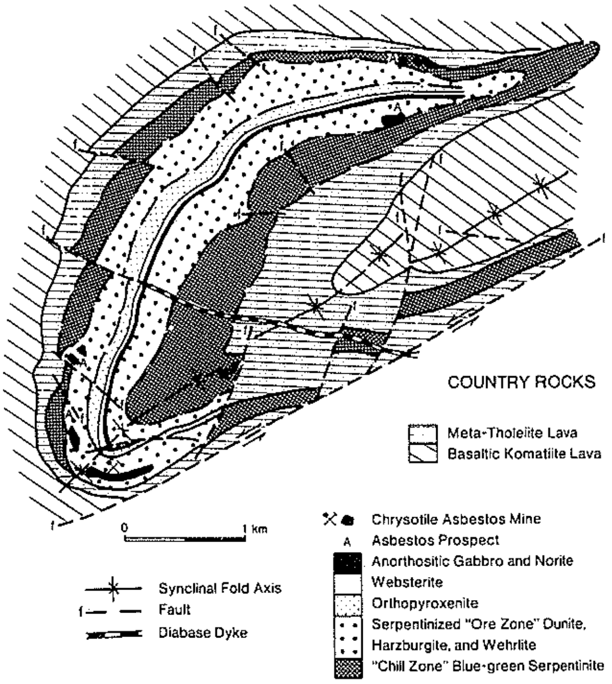

Figure 3

Geological map of the Koedoe layered intrusion near Malelane, Barberton District (after Viljoen and Viljoen, 1970).

The massive ultramafic pods usually consist of serpentinized dunite and pyroxenite. The cyclically differentiated bodies are characteristically dominated by ultramafic components (mainly dunite, harzburgite, and orthopyroxenite) with subordinate websterite, gabbro, norite, and anorthositic gabbro–norite phases (Figs. 3, 5, and 8), and minor rodingite and pegmatite (Viljoen and Viljoen, 1970; Anhaeusser, 1979, 1985; Wuth, 1980).

Only rarely does any one cycle display the full range of rock types. The most complete sequence is probably in the lower cycle of the Ship Hill, Budd, and Koedoe layered intrusions (Fig. 3). In multicyclical complexes such as the Stolzburg Intrusion (Figs. 5 and 6), rock assemblages in individual cycles commonly vary progressively from base to top, but in other sills incomplete or repetitive cycles may be developed. Some complexes, again like Stolzburg, can be further subdivided into a lower division, made up essentially of repetitive cycles of dunite and orthopyroxenite, and an upper division consisting of cyclic units comprising mainly harzburgite, websterite, and gabbro. The boundaries between lithologic units are generally sharp, suggesting crystallization layering. In places gradational contacts exist between orthopyroxenites and websterites and between the gabbroic, noritic, and anorthositic units in the upper parts of the layered sequences.

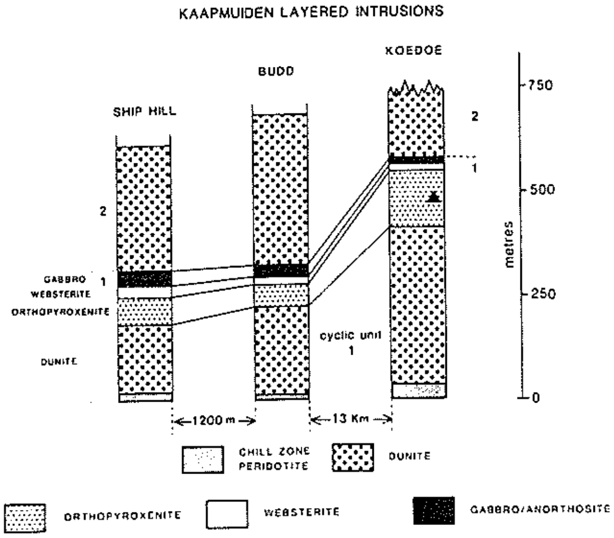

Figure 4

Stratigraphic columns for the Koedoe, Budd, and Ship Hill layered intrusions (after Viljoen and Viljoen, 1970).

Deformation, involving folding and faulting, has influenced most of the layered complexes. Invariably the successions exposed are steeply dipping and in some places the layered intrusions occur as disharmonic folds developed adjacent to subvertical detachment (décollement) faults (Figs. 3 and 7). The folding and faulting has played a dominant role in the development of chrysotile fibre (Anhaeusser, 1976) and almost all the asbestos mines are in or near fold hinges, or are near faults or zones where differential movement has taken place between layers of varying competency. Where deformation has been more intense the usually massive units have undergone severe flattening or shearing and mafic and ultramafic schists are developed. In some places schistose zones are confined to select stratigraphic units or are developed at phase contacts. Differential movement between layers in disharmonic folds (Figs. 7 and 8) has also produced schists as well as unusual ultramafic "slates" (Anhaeusser, 1969, 1972; Wuth, 1980).

2. *Upper Part of Volcanic Sequence*

Little is known about the layered ultramafic complexes in the mafic-to-felsic upper volcanic stratigraphy of the Barberton greenstone belt. The only published details relate to the Rosentuin Intrusion (Fig. 2) which, according to Viljoen and Viljoen (1969b), is a thick, crystal-segregated, lava flow overlying a sequence of pillowed tholeiites, altered felsic flows, and a discontinuous, layered, black and white chert unit. Serpentinized dunite, wehrlite, or lherzolite form the lower 76 m of the ultramafic intrusion, and pyroxenite, mainly websterite, forms the upper zone which is about the same thickness. Brecciated and carbonated agglomerate, felsic flows, and a grey-green chert overlie the ultramafic intrusion.

According to Viljoen and Viljoen (1969b) most of the other ultramafic rocks in the upper volcanic sequence are concordant sill-like intrusions closely associated with chert

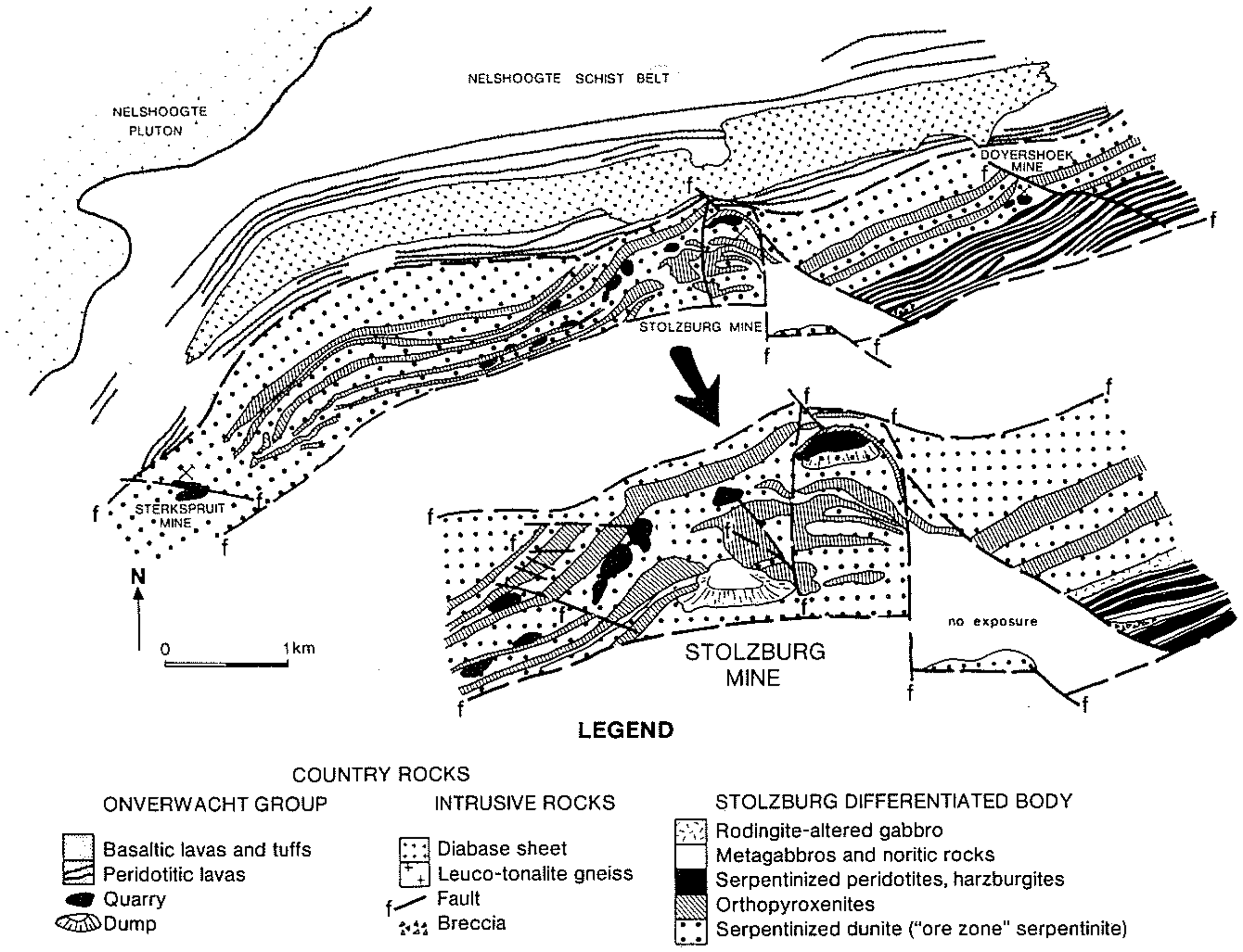

Figure 5
Geological map of the Stolzburg layered intrusion showing the cyclically repetitive nature of the subvertically dipping differentiated sequence which youngs to the south-east. Lower division cyclic units consist of dunite and orthopyroxenite. Harzburgite, websterite, gabbro, and anorthositic gabbro–norite make up the cyclic units of the upper division of the intrusion. The diabase sheet north of the Stolzburg Intrusion is known as the Sterkspruit gabbro intrusion (after Anhaeusser, 1976, 1985).

layers and showing signs of magmatic fractionation. The largest of these is the Msauli–Havelock Intrusion (Fig. 2). Recent investigations suggest that this important asbestos-bearing complex, which now consists almost entirely of serpentinite and steatite, formed from an alternating sequence of dunite, pyroxenite, and subordinate gabbro (Büttner, 1983; Barton, 1982, 1985, Voight *et al.*, 1985).

C. Field Relations and Petrography of the Best-Preserved Intrusive Complexes

The general nature of the Barberton intrusive complexes is exemplified by the four best exposed and least altered layered intrusions shown in Figs. 3, 5 and 7. Although widely separated along the north-western flank of the Barberton greenstone belt (Fig. 2) these intrusions show a considerable degree of similarity. In order to avoid repetition their principal characteristics will be discussed together in this section.

1. Structure

All four layered complexes outcrop prominently, with the most resistant units being pyroxenite. In some places, as for example in the Mundt's Concession Intrusion (Fig. 7), dunites and harzburgites also form resistant ridges. The layered sequences are generally steeply dipping and many are internally folded. The Koedoe Intrusion (Fig. 3), is exposed in an asymmetrical syncline with a wide, open, north limb and a poorly developed, tectonically aborted, south limb. The fold axis plunges 60° east-north-east parallel to a major left-lateral strike slip fault which acted as a detachment plane during the development of the fold structure (Viljoen and Viljoen, 1970). The Handsup Intrusion (Fig. 7) is also folded adjacent to a left-lateral strike-slip fault and represents a disharmonic anticlinal fold structure plunging steeply to the north-east (Anhaeusser,

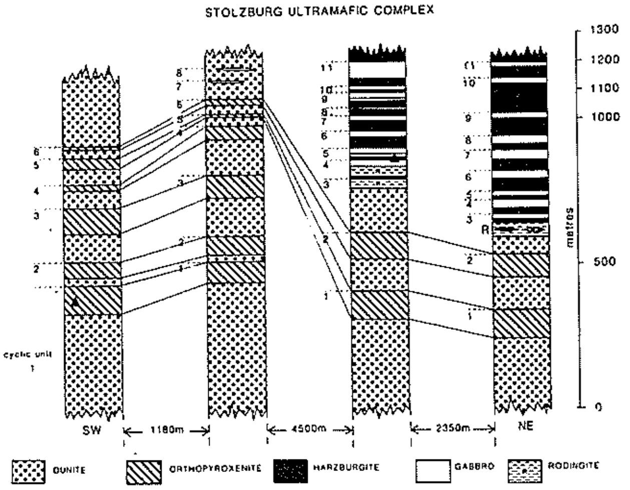

Figure 6
Stratigraphic columns across various parts of the Stolzburg layered intrusion. The south-western sections are dominated by alternating dunite–orthopyroxenite cycles (lower division), whereas those further north-east have uppermost cycles consisting mainly of alternating harzburgite and gabbro (upper division).

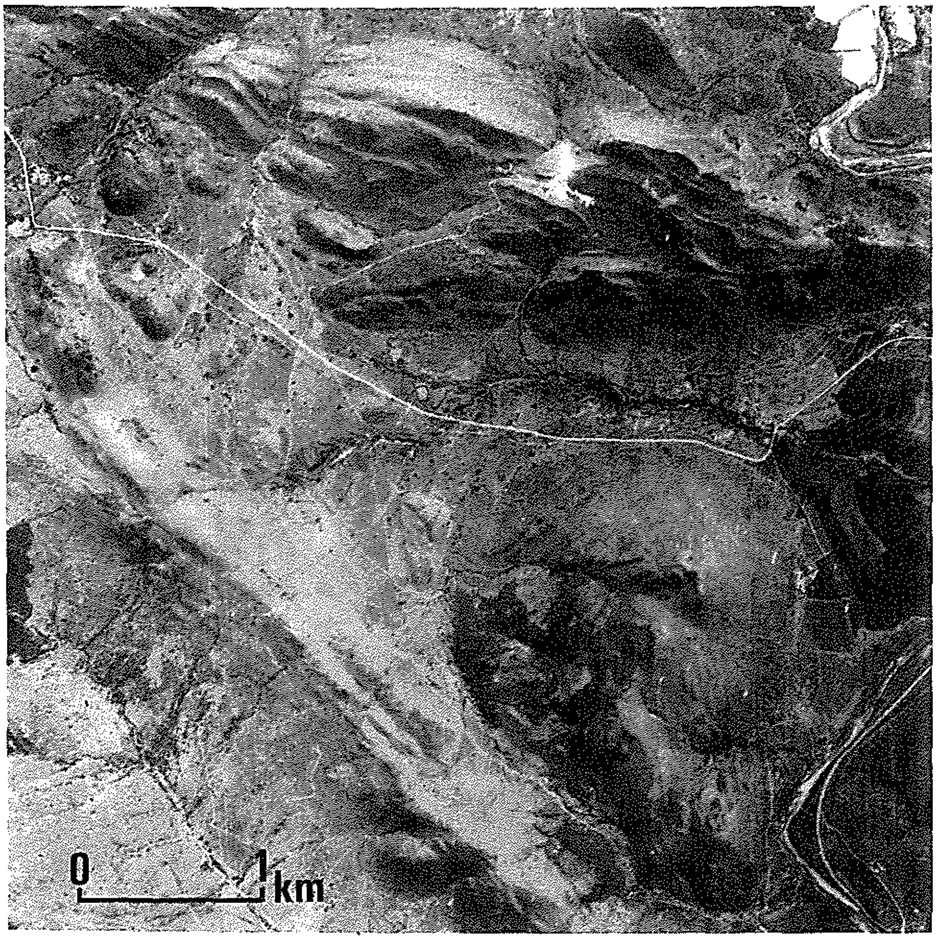

Figure 7

Aerial photographic view of the Handsup layered intrusion (disharmonic fold, lower right, produced by left-lateral detachment along the north-west-striking Albion Fault, Anhaeusser, 1972) and the Mundt's Concession layered intrusion (anticlinal fold, upper half of photograph). The Handsup and Mundt's Concession layered complexes are part of the same succession, but are separated by zones of shearing. Chrysotile asbestos has been mined from the dunite in the core of the Mundt's Concession fold (Marbestos Mine). The layering consists of cyclically repetitive units of dunite, harzburgite, pyroxenite, and gabbro (Fig. 8). Shearing has produced a variety of mafic and ultramafic schists in the area and quartz-feldspar porphyry intrusives are responsible for the development of small talc deposits. Verdite, a semiprecious variety of serpentine, and gold have been mined from small deposits in the region illustrated.

1972). North of the Handsup Intrusion is another major anticlinal fold within which the Mundt's Concession layered intrusion is exposed. The attitude of this anticline is not known precisely, but is believed to be subvertical. Although the area between the two intrusions is poorly exposed and is strongly tectonized north of the Albion Fault (Fig. 7), the Handsup–Mundt's Concession intrusions are considered to be part of the same layered complex because both have almost identical cyclically repetitive lithologic units. The Stolzburg Intrusion (Fig. 5) is, by contrast, fault bounded and the regularly layered, south-east-facing sequence either dips vertically or is overturned steeply to the north-west. In the south-east, Archaean sediments, that are younger than the intrusion, are in fault contact with the intrusion, but the north-western contact is conformable with komatiitic pillow basalts and ultramafic flow units. The regular layering is locally disturbed by cross faults which offset the stratigraphy and caused localized folding, as in the Stolzburg Mine area.

2. *Layering*

The Stolzburg, Handsup, and Mundt's Concession intrusions display multiple cyclical layering. The Koedoe Intrusion, by contrast, shows incipient cyclicity.

In the Stolzburg Intrusion many of the cycles in the lower division appear to have been cut out to the north-east by faulting (Fig. 5). Although at least 12 cyclic units are present in this intrusion in the Doyershoek Mine area, there may have been as many as 16 cyclic units if the correlations shown in Fig. 6 are correct. The lower cycles form most of the intrusion and are alternating serpentinized dunite layers (olivine cumulates) and generally altered, but in places remarkably fresh, orthopyroxenite layers (enstatite, bronzite cumulates). The dunite and orthopyroxenite layers vary in thickness from a few metres to 480 and 120 m, respectively (Figs. 5 and 6). Both rock types are mainly massive to locally schistose and primary structures within layers are absent. The upper cycles in the Doyershoek Mine are mainly serpentinized harzburgites and peridotites (including lherzolites and wehrlites), pyroxenites (ortho- and clinopyroxenite-websterite), and altered gabbros, norites, and anorthositic gabbros. The harzburgite and gabbro layers in the upper division are generally thinner than layers in the lower division and range in thickness from a few metres to a maximum of about 100 m for harzburgite, and to 50 m for gabbro. The upper division layers are also generally massive, except for fine layering in some gabbroic rocks, and schistose where deformation has been more severe. The harzburgite layers are locally gradational into pyroxenites, and the gabbros are likewise gradational into norites and anorthositic gabbros.

In the Stolzburg Intrusion a zone of calcium metasomatism, varying in thickness from a few metres to about 80 m, separates the monomineralic cumulates (dunites, enstatites, bronzitites) from the upper units which contain two or more cumulate mineral phases (harzburgites, lherzolites, wehrlites, websterites, diopsidites, gabbros). In this zone of prominent calcium enrichment rodingites occur either in the form of dykes or as irregular pods, or conformable replacement bodies closely associated with, and gradational into, the lowermost gabbroic rocks of the upper divison of the intrusion (Anhaeusser, 1979).

The Handsup layered intrusion consists of at least nine cyclic units (Figs. 7 and 8). In the lower part the cyclic units contain dunites, whereas higher in the succession harzburgites become progressively more prominent. The interlayered pyroxenites are dominantly websterites, but in places some serpentinized orthopyroxenites are present. In the upper cycles the amount of gabbro associated with the clinopyroxenites increases and there is a corresponding decrease in harzburgite. In the Mundt's Concession Intrusion dunites and harzburgites predominante (Figs. 7 and 8) and at least five cyclic units are terminated by thin clinopyroxenite or gabbro layers. The sequence in the Mundt's Concession Intrusion is most similar to the core zone (lower division?) of the folded Handsup Intrusion (Fig. 7) where dunites and harzburgites and their schistose equivalents predominate over pyroxenites and gabbros (Fig. 8). Intraformational shearing within the cyclic units has produced mafic and ultramafic schists and "slates", particularly in the Handsup fold structure. A number of verdite occurrences (semiprecious dark green variety of serpentine) are present in the Handsup Intrusion, generally at the contacts between harzburgite and pyroxenite–gabbro layers (Anhaeusser, 1972). Small quartz-feldspar porphyry bodies intruded the crestal zone of the Handsup fold and are locally responsible for the development of talc deposits.

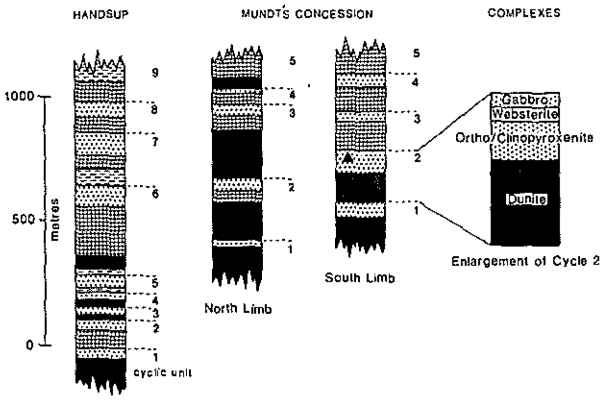

Figure 8
Stratigraphic sections across the Handsup and Mundt's Concession ultramafic complexes illustrating the multi-cyclical nature of the layering (after Anhaeusser, 1985).

The Koedoe Intrusion consists of a lower, complete, cyclic unit commencing with a basal peridotitic chill zone overlain, in turn, by zones of dunite, orthopyroxenite, websterite, and anorthositic gabbro–norite (Figs. 3 and 4). This is overlain by an upper incomplete cyclic unit of dunite in which occur a number of intrusive pods of coarse-grained pegmatite.

There is evidence for both cryptic and crystallization layering in these and other intrusions in the Barberton region, but rhythmic layering has not been recorded. In the anorthositic gabbro–norite zones of some layered complexes (e.g. Koedoe and Stolzburg) there is a type of layering characterized by thin layers less than 25 mm thick which may be repeated many times. These regularly repeated layers (*inch-scale-layering*) consist of alternations of pyroxene and plagioclase (Anhaeusser, 1985).

Crystallization layering is considered responsible for the laterally persistent cyclic units like those so well displayed in the Stolzburg Intrusion. According to Jackson (1970) such cyclic units probably represent a series of events involving simple fractionation and crystal settling in successive small batches of magma punctuated by the introduction of new magma batches into the zone of crystallization and settling. Without firm evidence to the contrary this explanation remains viable for the Barberton ultramafic complexes.

An alternative mechanism is that proposed by Cameron (1978, 1980) who suggested that changes in total pressure, causing shifts in phase boundaries on the liquidus, may have been the prime factor controlling the changes in mineral assemblages seen in layered sequences. Abrupt changes in total pressure could have been induced by tectonism affecting the shape of the chamber, temporarily reducing the lithostatic pressure of the roof rocks on the magma and shifting the boundaries on the liquidus until pressure was restored. A magma chamber might also lose pressure if it was successively expelling magma through some rupture feeding a developing volcanic sequence.

3. *Mineralogy and Petrography*

In the four complexes described above, the primary mineralogy appears to be relatively simple with most rocks consisting of olivine, orthopyroxene, clinopyroxene, and plagioclase in different combinations, varying proportions, and textural relationships. In the ultramafic rocks magnetite occurs in accessory amounts, whereas in the mafic phases magnetite, ilmenite, quartz, and rare sulphides may be encountered.

Alteration, resulting from serpentinization as well as regional and contact metamorphism, produced many secondary minerals (see Anhaeusser, 1985).

Original textures are frequently preserved even in some of the highly altered parts of the intrusions. Fine textural detail and crystal forms are preserved in most places, supporting the view that both serpentinization and metamorphic alteration has involved little or no volume change.

Cumulate rocks make up the bulk of the Barberton layered intrusions. The thin gabbroic layers, by contrast, generally have a fine-grained texture suggesting they may represent residual liquids, possibly filter pressed from spaces between solidifying cumulus crystals. In support of this Anhaeusser (1985) showed binary plots of SiO_2 and CaO versus MgO for rocks of the Stolzburg Intrusion indicating that the gabbroic components fall within the range of komatiitic basalt lava flows similar to those in the Nelshoogte Schist Belt flanking the layered intrusion.

Details of the petrology and geochemistry of the principal rock types encountered in the Barberton layered complexes were provided by Viljoen and Viljoen (1970) and Anhaeusser (1976, 1985). In the section which follows the main mineralogical findings are summarized.

Basal contacts of the layered bodies can be examined only in the Koedoe, Ship Hill, and Budd intrusions where fine-grained chilled peridotites lie directly on banded chert-amphibole sediments (Viljoen and Viljoen, 1970). The chilled peridotites are strongly altered, rendering the rocks unsuitable for the accurate determination of the bulk chemical composition of the parental magma which gave rise to the differentiated ultramafic bodies. The data does, however, suggest that the parent magma was of a high-Mg komatiitic variety.

Dunite layers invariably alternate in the layered complexes with orthopyroxenite layers, the two rock types generally forming a typical cycle near the base of the intrusions (e.g. Stolzburg, Figs. 5 and 6). Relative to the orthopyroxenites the dunites are less resistant to weathering and commonly have a distinctive yellow-green to grey colour in outcrops. These rocks, which are extensively serpentinized, are the main host to important deposits of chrysotile asbestos, magnesite, and talc (Anhaeusser, 1976).

The dunites contain more than 70 per cent cumulus olivine or its alteration products, mainly antigorite, talc, and tremolite. Only rarely are olivine remnants found in antigorite pseudomorphs which replaced the original 1- to 10-mm diameter olivine grains.

Altered intercumulus material, now consisting mainly of antigorite, talc, and chlorite, was probably originally orthopyroxene with lesser amounts of clinopyroxene. Chrysotile veins and stringers commonly occur within individual altered olivine crystals in the dunite or as cross-cutting fibre veins large enough and sufficiently densely developed to warrant exploitation as chrysotile asbestos deposits.

Cumulus magnetite occurs rarely in the Stolzburg Intrusion in thin (2–5 cm) primary layers, but is more common as an accessory primary phase, or as secondary magnetite developed around the margins of antigorite pseudomorphs after olivine and in veins and fractures in the dunites. Chromite is present in some intrusions as an accessory mineral and in places the cores of the chromite grains are replaced by the carbonate mineral stichtite, which is also recognizable megascopically as tiny, violet grains or coatings along cracks or parting planes in serpentinized dunites (Visser *et al.*, 1956).

Orthopyroxenite layers are invariably associated with dunite- or harzburgite-bearing cyclic units and form topographically distinct ridges in most of the layered intrusions. In the field they are massive, coarse-textured layers that are generally structureless, except for some jointing, and outcrops have a distinctive brownish-red surface weathering. Fresh surfaces have a dark waxy greenish colour, but are mostly dark blue-green where serpentinized. Cumulus orthopyroxene comprises more than 90 per cent of these layers with minor clinopyroxene and plagioclase as intercumulus phases. Olivine is generally absent, but accessory magnetite and chromite are locally encountered. Some orthopyroxene cumulates appear to have little or no intercumulus material and are monomineralic.

As with the dunite cumulates the orthopyroxenites are extensively altered but, in places, exceptionally well-preserved remnants remain. Alteration to bastite and talc is variable: in some places the orthopyroxenite is completely unaltered, but only metres away it may be partly or totally altered. Alteration begins with veins and stringers of talc and bastite penetrating fractures and cleavage planes in orthopyroxene crystals. More advanced alteration results in talc or bastite pseudomorphing the orthopyroxene. Microprobe analyses of fresh orthopyroxenes from the Koedoe and Stolzburg intrusions confirm that enstatite and bronzite are the principal cumulate phases in the orthopyroxenite layers (Anhaeusser, 1985).

The cyclic units in the Stolzburg, Handsup, and Mundt's Concession intrusions contain local harzburgite layers that occur in the field as massive, dark, bluish-black to grey ridges. In other layered intrusions harzburgites are the most widespread rock type and are dark brown on weathered surfaces. Orthopyroxene megacrysts, possibly representing large cumulus crystals up to 3 cm in length, form either positive or negative weathering features (Wuth, 1980).

Cumulate phases generally include variable abundances of olivine, orthopyroxene, and chromite but, in places, the rocks also contain cumulate clinopyroxene and can be regarded as lherzolite. In rare instances olivine and clinopyroxene are the only major cumulus minerals and the rock is wehrlite. Although these layers are generally altered to serpentinite there are zones where relic olivine kernels are preserved or where partly altered olivine crystals occur poikilitically encased in orthopyroxene megacrysts. The olivine crystals vary in size from 0,2 to 3 mm and the less common orthopyroxenes and clinopyroxenes average 3 to 0,5 mm, respectively. Anhaeusser (1985) showed that the olivine in these rocks ranged in composition from Fo_{88} to Fo_{90} and the orthopyroxene poikilitically enclosing the olivine is enstatite (En_{90}).

Intercumulus phases are obscure, but probably consist mainly of clinopyroxene altered to tremolite and forming the matrix between ovoid antigorite which is pseudomorphous after olivine. Secondary magnetite, released from the olivine during serpentinization is ubiquitous, and minor amounts of talc, chlorite, and chrysotile are common, but no economic asbestos deposits have yet been found in altered harzburgite.

Clinopyroxene-rich layers occur in the upper parts of some of the Barberton ultramafic intrusions. These relatively thin layers generally form low, sparse outcrops that are commonly obscured by talus from neighbouring dunite, orthopyroxenite, and harzburgite ridges. Locally, however, websterite forms conspicuous ridges in the Koedoe and Sawmill intrusions and to a lesser extent in the Handsup and Mundt's Concession intrusions (Anhaeusser, 1969, 1972; Viljoen and Viljoen, 1970; Wuth, 1980).

In the field the websterite is pale greenish-grey and typically consists of 50 to 75 per cent stubby, randomly orientated crystals of clinopyroxene, 0,2 to 1 mm in size, and 25 to 40 per cent somewhat larger orthopyroxene crystals (Viljoen and Viljoen, 1970; Wuth, 1980). In the Handsup–Mundt's Concession intrusions orthopyroxene is less abundant and the cumulus phases are mainly tabular or stubby clinopyroxene crystals and subordinate orthopyroxene with minor intercumulus plagioclase.

Microprobe analyses of clinopyroxenes in websterite from the Mundt's Concession Intrusion indicate that the cumulus mineral is endiopside with compositions of about $Ca_{39}\ Mg_{51}\ Fe_{10}$ (Anhaeusser, 1985). Depending upon the relative amounts of clinopyroxene, orthopyroxene, and plagioclase the rocks may be referred to as diopsidite, websterite, or norite–gabbro. These rock types are more or less transitional into one another, particularly in the Koedoe Intrusion.

Alteration is prevalent with the clinopyroxene uralitized to tremolite–actinolite, the orthopyroxene altered either to chlorite, bastite, or less commonly talc, and the plagioclase converted entirely to albite, or saussuritized to epidote or clinozoisite.

Plagioclase is a prominent, but variable, constituent of anorthositic gabbro–norite zones. Rocks of gabbroic affinity commonly terminate cyclic units and in the field are generally poorly exposed forming troughs or hollows between more resistant ultramafic components. They are usually overlain by harzburgites of the immediately following cyclic unit and are partly or wholly buried beneath scree from the ultramafic ridges. Some of the best exposures of gabbroic rocks are in the Handsup, Mundt's Concession, and Stolzburg intrusions where they demonstrate the variability produced by changing proportions of plagioclase and ferromagnesian components. They generally have medium- to fine-grained intergranular to subophitic textures, but locally they are coarse textured and almost pegmatite-like in character. As mentioned earlier some of the gabbroic rocks may not be cumulates, but rather residual liquids or magma left over following crystallization of earlier-formed phases.

The plagioclases are generally replaced by albite or oligoclase, and the pyroxenes by tremolite–actinolite or chlorite. In addition to the albitization of plagioclase there have been variable degrees of saussuritization and sericitization. Where unaltered the plagioclase is very calcic. In the Koedoe Intrusion a 12 m-thick anorthositic gabbro–norite layer contains up to 60 per cent plagioclase, intercumulus clinopyroxene, and, less commonly, large cumulate orthopyroxene grains. In some places the plagioclase is little altered and, in the more anorthositic rocks, Viljoen and Viljoen (1970) reported compositions ranging from An_{92} to An_{94}. Quartz is present in some areas and accessory minerals include variable amounts of magnetite, ilmenite, sphene, and leucoxene.

Other variations encountered in the anorthositic gabbro–norite layers include the development of rodingites or garnetized gabbros (Anhaeusser, 1979), inch-scale layering of clinopyroxene- and plagioclase-rich layers, and zones where the gabbros have fine- to coarse-grained textures and locally pegmatitic fabrics, and are intruded by irregular plagioclase- and quartz-rich veins and dykes.

Discordant pods and irregular bodies of coarse-grained pegmatite have been recorded in some complexes. In the Koedoe and Ship Hill intrusions, Viljoen and Viljoen (1970) noted that pegmatite occurs mainly in the upper dunite layer overlying the basal differentiated sequence. In the Stolzburg Intrusion pegmatite-like patches occur in some of the gabbroic phases.

The pegmatites generally contain large, elongated blades of tremolite–actinolite, up to 10 cm long, that have replaced the original diopsidic augite. These are surrounded by large plagioclase laths that have been partly saussuritized to epidote or clinozoisite.

In the Stolzberg, Sawmill, and Pioneer intrusions rodingites occur as dykes or as irregular pods or replacement bodies closely associated with, and gradational into, gabbroic rocks, and as dykes in serpentinized dunites (Anhaeusser, 1979; Wuth, 1980). The dykes generally have positive relief relative to the surrounding serpentinites and gabbros and are readily identified by their characteristic buff, or pale flesh-pink-coloured, weathered surfaces, although some dykes are pale greenish-grey or white. In the Stolzburg Intrusion the dykes vary in width from a few centimetres to more than 5 m.

The rodingites, which have also been recorded in the Havelock Mine (Barton, 1985), are mineralogically complex rocks and contain a wide variety of calcium-rich minerals including hydrogrossular, hibschite, vesuvianite, diopside, nephrite, prehnite, zoisite, and many others. Their origin is believed to be multifaceted, but broadly involves the release of calcium from Ca-rich mineral phases such as clinopyroxene and plagioclase and the preferential metasomatic replacement of suitable host rocks, such as dykes in the serpentinized dunites, and dykes, lenses and zones in the gabbroic rocks (Anhaeusser, 1979).

D. Other Layered Complexes

In addition to the layered complexes described above, and which represent the best-preserved Archaean examples known in Southern Africa, there are a number of other layered intrusions in the Barberton Mountain Land that merit consideration mainly because they host important chrysotile asbestos deposits. Some of these deposits are still being exploited, but many have been exhausted.

1. *Kaapsehoop*

The Kaapsehoop Intrusion is situated at the north-west end of the Jamestown schist belt where it extends beneath the Proterozoic cover rocks of the Transvaal Drakensberg escarpment (Fig. 2). The layered body, which is folded and faulted, is host to the New Amianthus, Munnik Myburgh, and Sunnyside/Star asbestos mines (Fig. 9). The New Amianthus deposit is the only currently operating mine and is described by Laubscher (1985b). His account supplements the early work done in the area by Hall (1921, 1930) and Van Biljon (1964), and clearly illustrates host rock control, fibre growth mechanism, structural control, and the relative age of the fibre formation.

The Kaapsehoop ultramafic body is, according to Anhaeusser (1976), similar to the lower division of the Stolzburg body described earlier, in that it consists

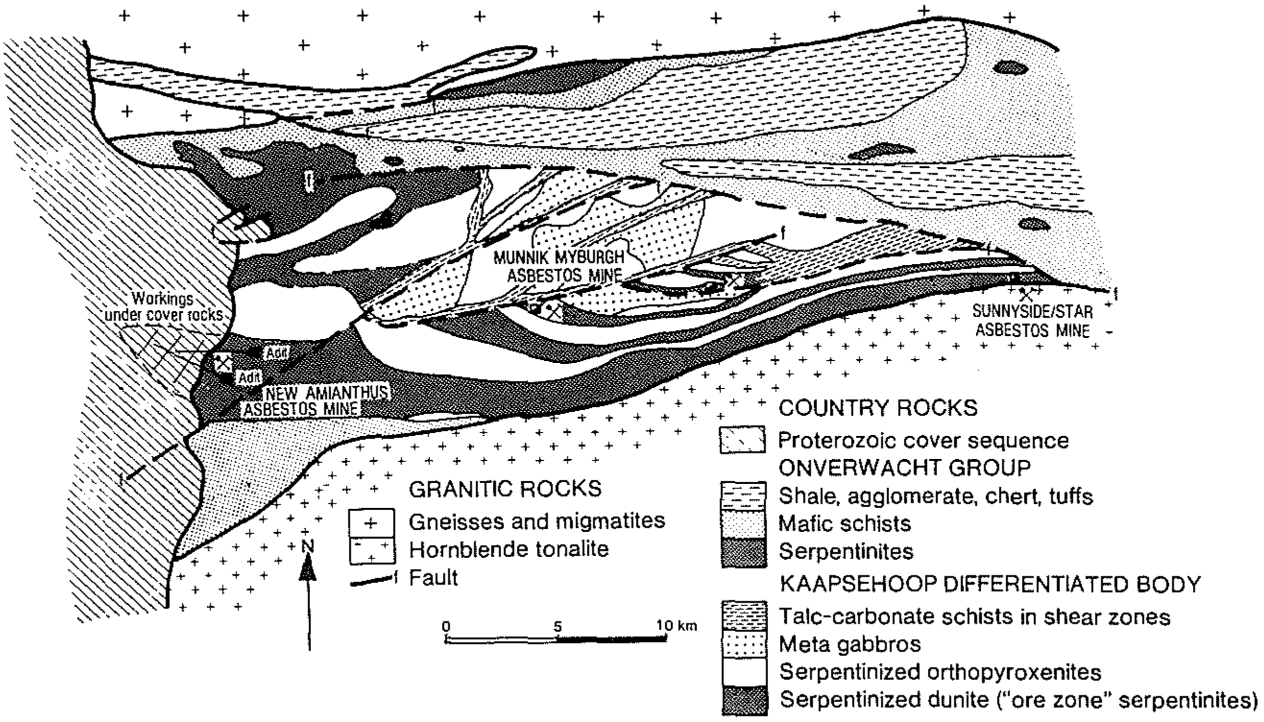

Figure 9

Geologic map of the Kaapsehoop layered intrusion 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).

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 and 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°. The fold plunges to the east at approximately 45°.

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 fibre generally occurs in the altered dunites where these are in contact with the altered pyroxenites. Differential movements between competent orthopyoxenites and less competent dunites are responsible for some of the ore bodies (e.g. Sunnyside/Star), although the effects of the faulting in the area must also be regarded as a contributing factor aiding fibre development. According to Van Biljon (1964) the "ribbon" nature of the fibre 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 fibre 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.

2. *Havelock–Msauli*

Two of the largest chrysotile asbestos deposits in Southern Africa, namely the Havelock and the Msauli ore bodies, occur in the south-eastern portion of the Barberton Mountain Land, in successions now classified in the Zwartkoppie Formation of the Onverwacht Group (Viljoen and Viljoen, 1969b; Barton, 1982, 1985; Büttner and Saager, 1982; Büttner, 1983; Voight *et al.*, 1985). In this region, the Zwartkoppie assemblages straddle the KaNgwane–Swaziland border and constitute the uppermost member of the Mafic-to-Felsic Unit outlined earlier. The main components of the Zwartkoppie Formation stratigraphy, in the area of the two mines, include green and grey 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) indicated that all of the serpentinite pods occur in the same stratigraphic position within the Zwartkoppie Formation, between cherts and related sediments which, in most cases, form the immediate footwalls and hanging walls of the ore bodies. The serpentinized ultramafic pods are thought to represent parts of a once continuous or nearly continuous differentiated sill emplaced penecontemporaneously with the remaining Zwartkoppie rocks and conformable with the latter.

3. *Kalkkloof*

The Kalkkloof layered intrusion is situated 15 km north of Badplaas and 20 km west of the Stolzburg Intrusion (Fig. 2). 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 intrusion consist predominantly of north-north-east-trending serpentinized dunites and orthopyroxenites with subordinate metagabbroic phases. The formations dip 45 to 60° north-west and the asbestos mineralization, as was the case in the Kaapsehoop body, occurs in the form of parallel seams (ribbon fibre) 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), Van Biljon (1964), and Menell *et al.* (1985). At least five fibre-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 dykes occur in the mine area and Van Biljon (1964) indicated that fibre development is confined almost entirely to the western side of a prominent fault-dyke which cuts the body in a north–south direction. He further suggested that a genetic relationship exists between the faulting and asbestos fibre formation.

4. *Rosentuin*

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) and lherzolite (olivine plus diallage plus orthopyroxene) 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 dyke 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 controlled by the contact of the "ore zone" serpentinite with a resistant peridotite layer within the body. The fibre produced from this area was, however, of a semi-brittle, poor quality.

IV. MULDERSDRIF ULTRAMAFIC COMPLEX, KRUGERSDORP DISTRICT

The Muldersdrif layered complex is situated approximately 25 km north-west of Johannesburg (Fig. 1), in an Archaean remnant on the western extremity of the Johannesburg basement granite dome. Although extrusive ultramafic and high-Mg 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. 10). Correlated with the Lower Ultramafic Unit of the Barberton model, 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, 1978).

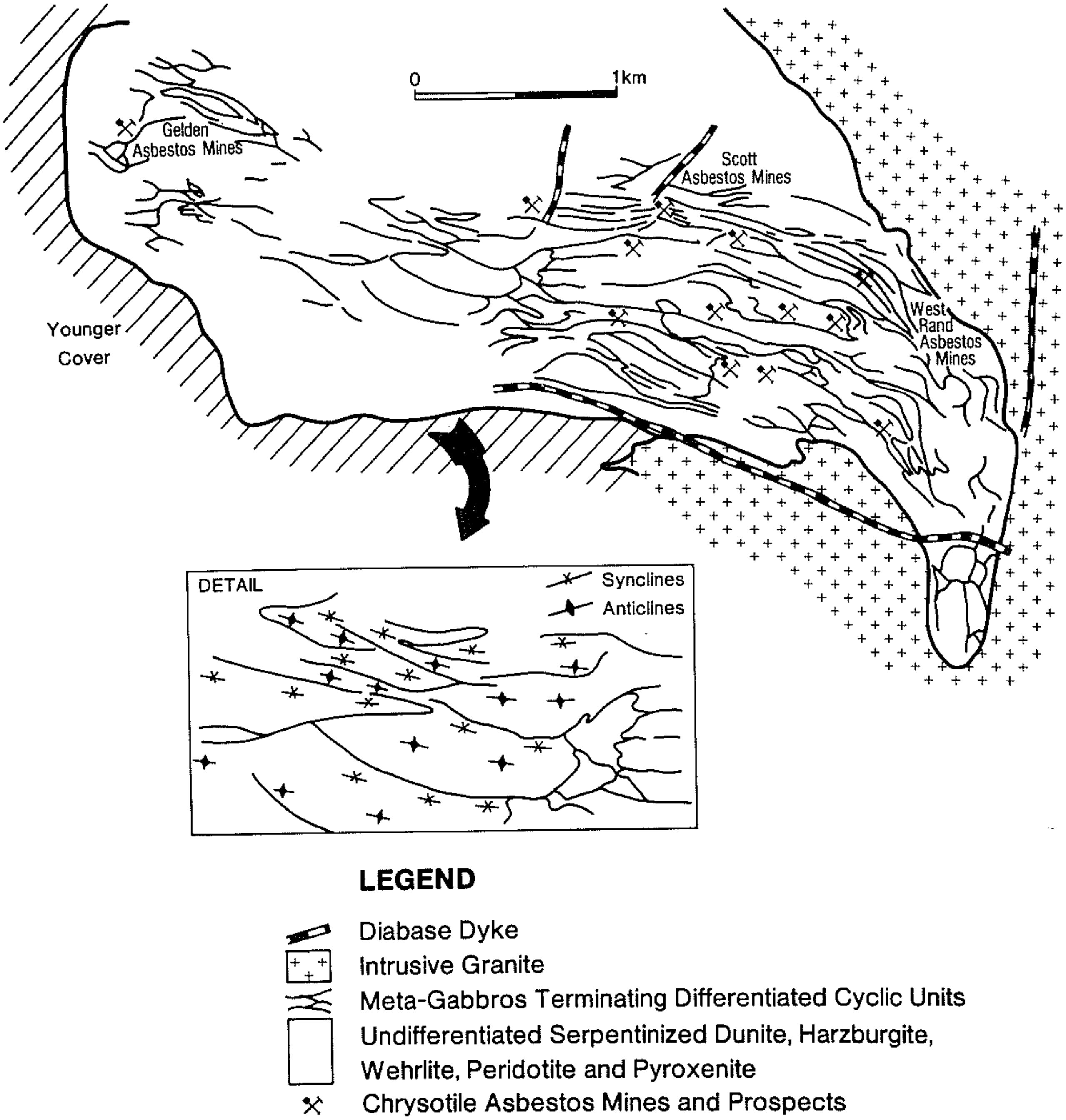

Figure 10

Simplified map of the complexly folded Muldersdrif layered ultramafic intrusion situated north-west of Johannesburg (see Fig. 1). Chrysotile asbestos fibre is developed mainly along the contacts between serpentinite (altered dunite) and metagabbro layers (modified after Anhaeusser, 1976, 1978).

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.

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. 10). The development of chrysotile asbestos appears to have been largely dependent on the style of deformation and on the composition of the deformed host rocks. Almost invariably the asbestos fibre 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 fibre 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 fibre. Numerous prospects occur in the region, but no subsequent mining has been attempted.

V. CHRYSOTILE ASBESTOS-BEARING ULTRAMAFIC COMPLEXES IN ZIMBABWE

A. Mashaba Complex

The Mashaba Complex occurs at the western end of the Fort Victoria greenstone belt, in the southern part of Zimbabwe (Fig. 1). It forms a layered, predominantly ultramafic intrusion which can be divided into sheeted and dyke portions. The sheeted portion consists of four recognizable units, believed by Wilson (1968a, b) to represent separate injections of magma emplaced one beneath the other, with the oldest and most ultramafic pulse at the top. The dyke portion, considered to be the feeder of the intrusion, has the form of a discontinuous ring dyke. According to Wilson (1968a), the Mashaba Complex (Fig. 11) appears to have been emplaced after the main phase of folding which affected the rocks of the Fort Victoria greenstone belt. It was, however, intruded before the emplacement of a late Archaean granite which Wilson (1968b) has suggested represents a late-tectonic granite of post-Shamvaian age (~2 600–2 900 Ma old).

The successive magma heaves of the Mashaba 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 dykes were emplaced.

The entire sequence was subsequently deformed by the intrusion of granite and the Mashaba 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 south-east the Complex attains its greatest structural complexity, being intricately folded and faulted on a large scale (Fig. 11).

An important result of the deformation of the Mashaba Complex is the development of chrysotile asbestos fibre on an economic scale. Figure 11 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 fibre deposits (Wilson, 1968a, b; Laubscher, 1968). While this control is undoubtedly of great importance, Anhaeusser (1979) maintained that regard should also be taken of the regional and local fold patterns as major additional contributory factors in fibre localization. In support of this it can be seen that the majority of noteworthy asbestos showings are located in fold hinges or on fold limbs.

In the Mashava District approximately 75 per cent of all the asbestos has been produced from the Gaths and King mines, both of which are described in detail in this volume by Laubscher (1985a).

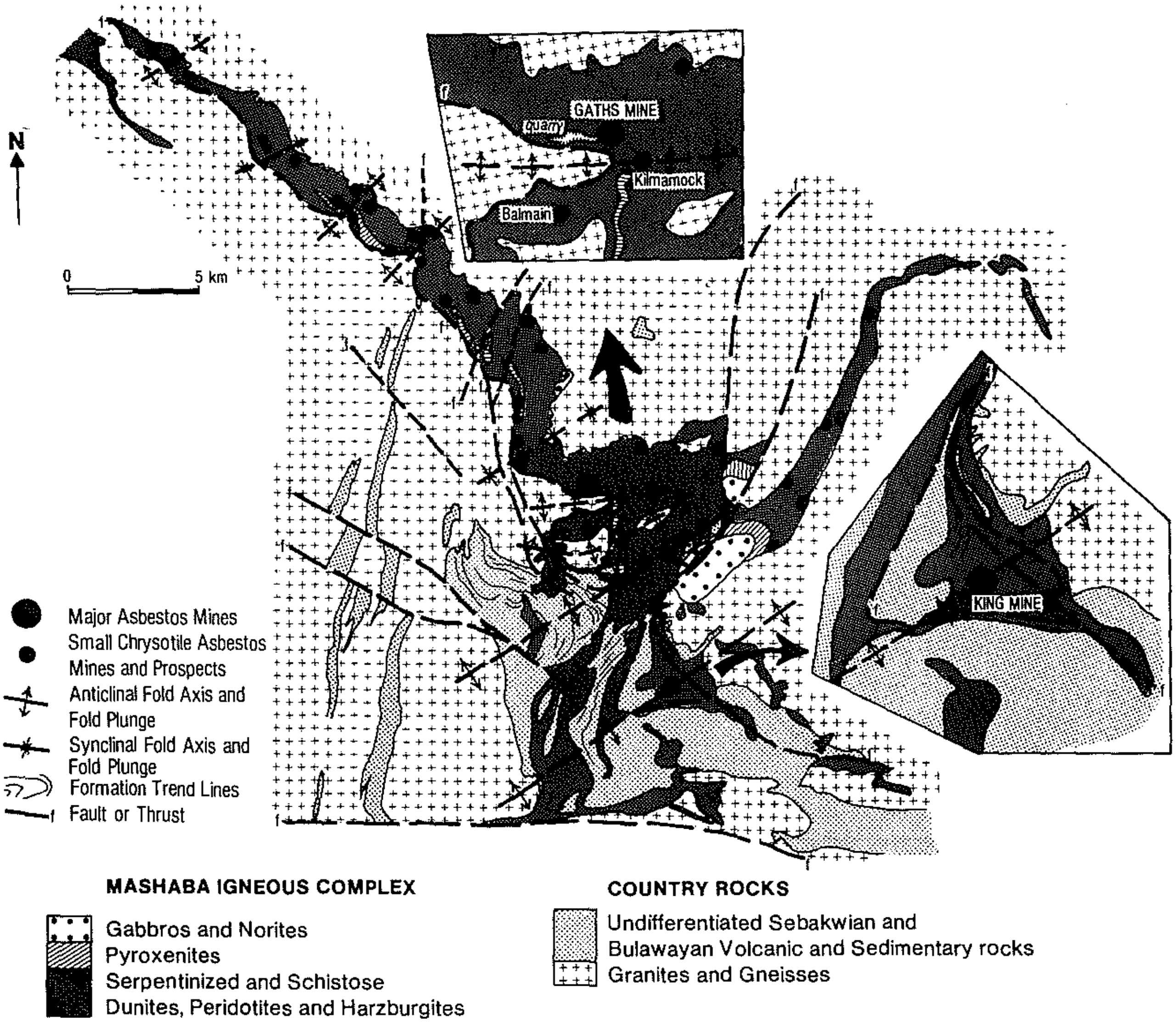

Figure 11

Geological map of the Mashaba Complex, Zimbabwe, showing the distribution of chrysotile asbestos occurrences in relation to faults, thrusts, and folds (modified after Wilson, 1968b).

B. Shabani Complex

A number of mafic and ultramafic layered intrusions, sills, and dykes have been identified in the central cratonic area of Zimbabwe (Wilson, 1979). The best documented are those of Mashaba and Shabani (Wilson, 1968a, b; Laubscher, 1964, 1968), mainly because they are the host rocks to important chrysotile asbestos and, to a lesser extent, chromite deposits. These, and several smaller ultramafic sills, intrude the crustal segment containing the major development of *c.* 3 500 Ma rocks. Wilson (1979) correlated the smaller intrusions with the Mashaba–Shabani intrusions themselves, but relationships with the granites in the region place them between the Mashaba tonalite (2 970 ± 160 Ma) and the Chilimanzi Suite of late granites (2 625 ± 25 Ma). It has been suggested by Wilson (1979) that these various ultramafic intrusions and dyke swarms are coeval with the thick, high-Mg to tholeiitic volcanic pile common to the western and eastern successions of the Upper Greenstones (Upper Bulawayan); and that the dykes were possibly feeders to some of the flows.

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

The geology of the Shabani asbestos deposits has been well documentated, first by Keep (1929) and later, in greater detail by Laubscher (1964, 1968). In this volume Laubscher (1985a) provides supplementary information on the geology and mineralization of the Zvishavane (Shabani) and Mashava (Mashaba) areas of Zimbabwe, and in this paper only the broad outlines of the Shabani Complex are discussed. Laubscher (1964) indicated that the Shabani ultramafic body has a strike length (north-west–south-east) of just over 14 km and a thickness of approximately 1,5 km (Fig. 12). A number of disconnected ore bodies are located in the central footwall dunite of the lenticular ultramafic sill which, according to Laubscher (1964), intruded into the Archaean gneisses along the north-east margin of the Belingwe greenstone belt.

The ultramafic mass 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 Shabani (Zvishavane) Township.

From base to top Laubscher (1964) recognized the following rock types, the distribution of which can be seen in Fig. 12: 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 fibre zone — 12 to 180 m in thickness representing a transition zone in the dunite of decreasing CO_2 metasomatism. Brittle fibre, which results from the replacement of chrysotile layers by magnesite and talc,

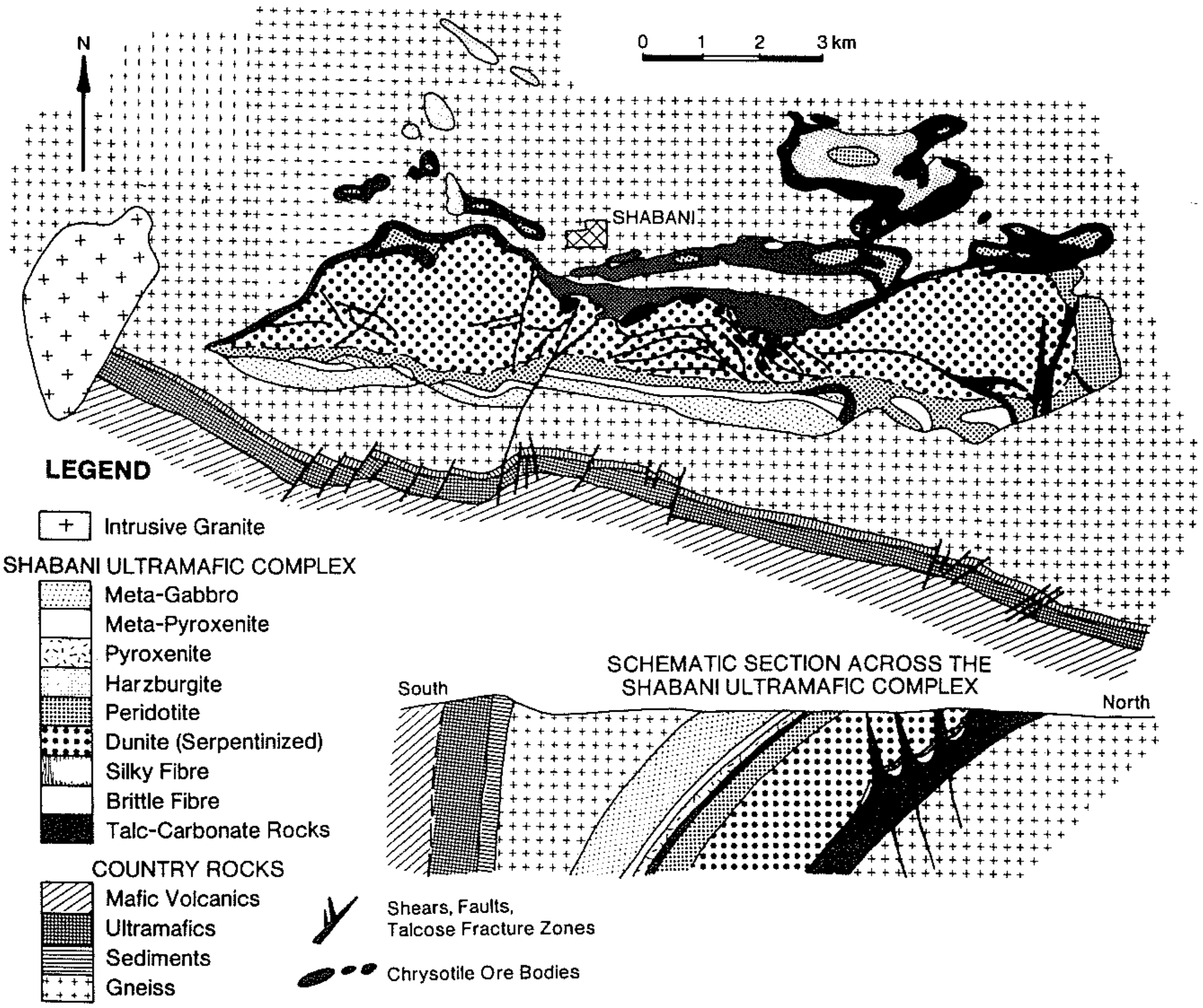

Figure 12

Map of the Shabani Complex, Zimbabwe, showing the distribution of the main chrysotile asbestos ore bodies (adapted from Laubscher, 1964).

gives way gradationally to silky fibre after first passing through a zone of harsh fibre; 3. silky fibre bodies—representing the good-quality fibre in the various ore bodies strung out along the central footwall dunite of the Shabani Complex. The ore bodies are commonly separated by zones of talc in CO_2-metasomatized fractures and faults; 4. partly serpentinized dunite—with a thickness of approximately 750 m, forming the bulk of the ultramafic mass. Remnant olivines are seen in places; 5. peridotites—occurring as an indefinite zone in the upper portion of the main mass and in the northern outliers (Fig. 12); 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 per cent orthopyroxene; 8. pyroxenites—found as lenticular bodies in the central and western hanging walls of the main mass (Fig. 12) 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 Shabani 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 and fissures, resulting in the development of carbonated serpentinites and the talc–carbonate zones separating the chrysotile ore bodies.

According to Anhaeusser (1976) 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 intrusion, the latter possessing the requisite chemical and textural properties necessary for the subsequent development of chrysotile fibre on a major scale.

C. Filabusi Complex

Chrysotile fibre-bearing serpentinite bodies occur in the Filabusi greenstone belt, which is located in the southern part of Zimbabwe, 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. Some of 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 (Fig. 13). They probably represent concordant sills in a succession of mafic volcanics similar to those of the Lower Ultramafic Unit. Wilson (1979) indicated, however, that a southerly dipping, sill-like body, known as the Gurumbatumba layered intrusion, extends through the region west of the Belingwe greenstone belt to north-west of Filabusi where it is truncated by granite. The Gurumbatumba–Filabusi Intrusion cuts not only the Lower Greenstones of the Belingwe and Filabusi belts, but also the gneissic granites intruded into them, including the Chingezi tonalite which has been dated at 2284 ± 92 Ma by Hawkesworth *et al.* (1979).

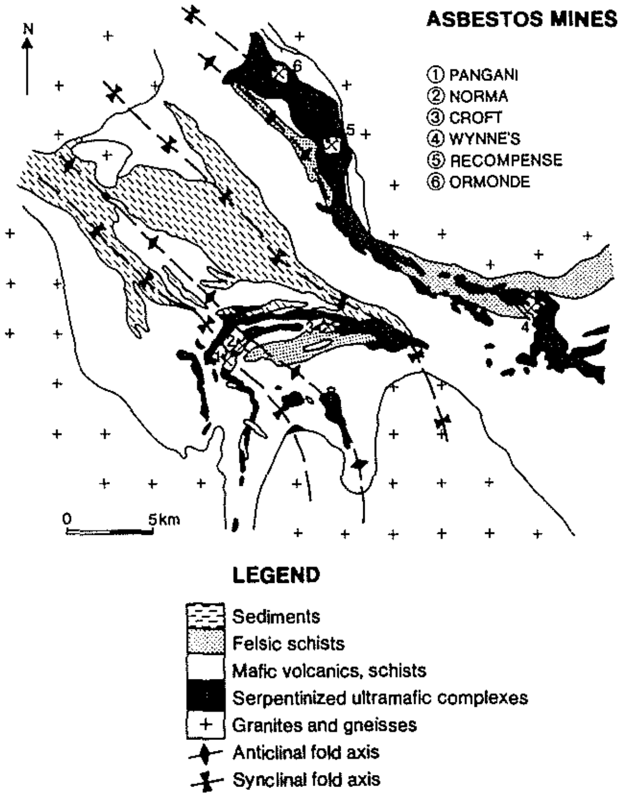

Figure 13

Geologic map of portion of the Filabusi greenstone belt, Zimbabwe, showing the distribution of asbestos deposits in the folded ultramafic bodies in the region. The ultramafic complex extending from the Ormonde to the Wynne's asbestos mines, and eastward, towards the Belingwe greenstone belt, is known as the Gurumbatumba–Filabusi layered intrusion (modified after Ferguson, 1934 and Wilson, 1979, 1981).

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 Fig. 13. It is evident that the economic fibre 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.

D. The Great Dyke

The Great Dyke of Zimbabwe, which is 2532 ± 89 Ma 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 dyke, 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 dyke laterally.

According to Anhaeusser (1976) the only producing mine on the Great Dyke was the Ethel asbestos deposit, situated near the northern end of the dyke (Fig. 1). The mine is located on the southern side of a fault which displaces the dyke more than 300 m (Fig. 14). In the mine the fibre 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 fibre formation.

The country rock of the asbestos was originally either harzburgite or dunite. The fibre 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.

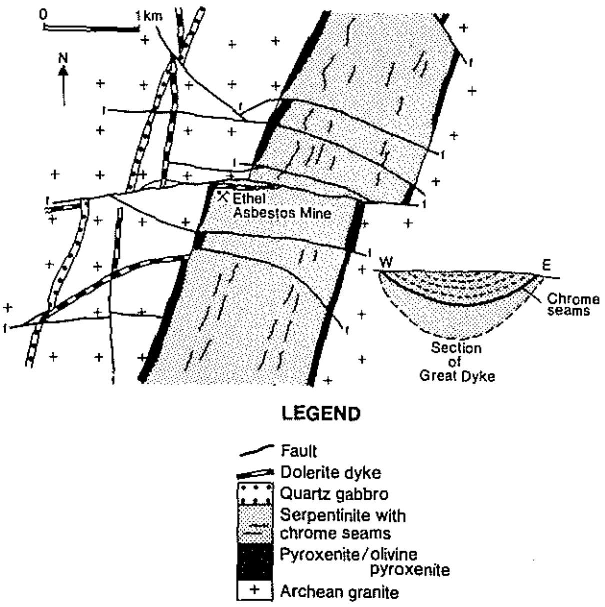

Figure 14
Chrysotile asbestos mineralization associated with faulting in the Great Dyke, Zimbabwe (adapted from Worst, 1960).

VI. CHRYSOTILE ASBESTOS IN THE TRANSVAAL SEQUENCE

Chrysotile asbestos deposits, derived by thermal alteration of dolomite, are known from around the Transvaal Basin, where dykes and sills have altered the Malmani Dolomite. The principal deposits, which have been described in detail by Hall (1930) and Van Biljon (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 (~2 000 Ma old), intruded into the dolomite, are particularly abundant. The sills commonly produce a metamorphosed assemblage extending for a metre 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, which is clearly pseudomorphous after chert, commonly displays delicate depositional structures such as ripple marks, algal laminations, and stromatolites (Button, 1974). Chrysotile asbestos is also developed in the serpentine. According to Van Biljon (1964), fibre formation is related to minor deformations in the dolomite. He was of the opinion that the fibre-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); and
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 intruded into chert-free dolomite, no fibre is developed; the second by the fact that the fibre is invariably found above the sill, the expected position of volatiles (Button, 1974).

In Fig. 15, a schematic section of the Eastern Transvaal escarpment region is given and the distribution of asbestos mineralization relative to the dykes and sills in the dolomites is illustrated.

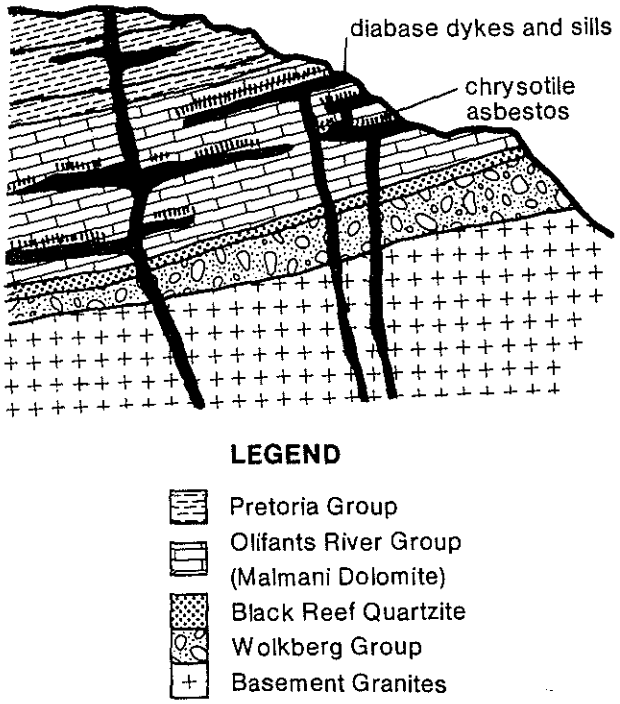

Figure 15
Schematic section illustrating the distribution of chrysotile asbestos mineralization above diabase sills intruded into dolomitic rocks of the Transvaal Sequence (after Button, 1974 and Anhaeusser, 1976).

VII. DISCUSSION AND CONCLUSIONS

It is evident, from the 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 ore bodies associated with the Proterozoic dolomitic rocks.

Undoubtedly, the prime requisite for the development of chrysotile fibre centres about the suitability of the host rocks. Chrysotile asbestos is only found in serpentinite and, as the latter forms as a result of the alteration of a wide variety of rock types (e.g. dunites, peridotites, harzburgites, wehrlities, 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.

The descriptions of the various chrysotile deposits in Southern Africa leave little doubt that the most favourable ultramafic host rocks for chrysotile fibre 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 reached a high degree of purity, the olivines and orthopyroxenes, for example, being particularly magnesium-enriched fosterites and bronzites or enstatites.

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 fibre development. These magmas, it has been established (Anhaeusser, 1969, 1976, 1985; Viljoen and Viljoen, 1969d), were komatiitic 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.

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 unsuitable for the development of fibre. Systematic structural studies in many asbestos deposits throughout the world have shown that cross-fibre asbestos seams require tensional conditions for fibre growth, whereas slip fibres are localized in planes along which shearing has taken place (Hall, 1930; Riordon, 1955; Laubscher, 1964, 1968; Van Biljon, 1964). Emphasis has largely been placed on faulting as constituting the most important fibre 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 fibre host rocks. Associated with the faulting would be areas where stress-controlled dilation seams could develop. Significantly, it is stated, fibre is best developed in those areas having the simplest structural pattern;
3. where wrench faulting is dominant, slip fibre is localized in the fault zone or sympathetic structures; and
4. the presence of structures which create the correct stress environment, allowing serpentine minerals to recrystallize to form fibre seams.

Whereas faulting undoubtedly played a prominent role as a fibre growth mechanism it was considered by Anhaeusser (1976) that some attention should also be directed to the significant role that folding plays in the localization of chrysotile ore deposits. Folding appears, in many examples, to be the dominant regional controlling factor for asbestos development, whereas faulting and fracturing provides the more localized control governing fibre growth and fibre density. In effect, the various fibre-controlling factors cannot be separated as they are intimately related, the one being dependent on the other.

Finally, although numerous Archaean layered intrusions are known from around the world, most are considerably less magnesian than the Barberton and other Southern African ultramafic intrusions. With few exceptions these intrusions are cyclically layered with dunite, peridotite, and harzburgite forming as much as 80 per cent by volume of some of the complexes; the balance usually consists of different varieties of pyroxenite. Plagioclase-bearing lithologies such as gabbro, norite, and, more rarely, anorthosite are present only in some of the larger complexes. The unique geochemical character of the Southern African layered intrusions has, therefore, been principally responsible for the development of important chrysotile asbestos and magnesite deposits in this region.

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