



ECONOMIC GEOLOGY
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RODINGITE OCCURRENCES IN SOME
ARCHAEOAN ULTRAMAFIC COMPLEXES IN THE
BARBERTON MOUNTAIN LAND, SOUTH AFRICA

C. R. ANHAEUSSER

— • INFORMATION CIRCULAR No. 116

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IN THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA

by

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ABSTRACT

Archaean layered ultramafic complexes in the Barberton greenstone belt, South Africa, consisting mainly of serpentinitized dunite, harzburgite, and orthopyroxenite, as well as websterite and gabbroic rocks, contain dykes and irregular pods and lenses of rodingite. The mineralogy of the rodingites includes the prominent development of a wide range of calcium-rich minerals such as hydrogrossular, hibschite, vesuvianite, diopside, nephrite, prehnite, zoisite, and others.

In addition to providing 11 chemical analyses of rocks representative of the Stolzburg Ultramafic Complex, five analyses of rodingites from the vicinity are listed for comparison with similar rocks from elsewhere in the world. A brief review of the nature of rodingites in general, as well as the various proposals that have been offered for their genesis, is included.

It is concluded, from investigations of the chemistry and mineralogy of various rocks in the Barberton layered complexes, that Ca-metasomatism, the latter related to serpentinitization of the ultramafic country rocks, played a dominant role in the development of these rodingite occurrences.

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RODINGITE OCCURRENCES IN SOME ARCHAEN ULTRAMAFIC COMPLEXES
IN THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA

I. INTRODUCTION

During the course of investigating some Archaean ultramafic complexes in the Barberton Mountain Land, South Africa, a number of unusual "white dykes" were encountered. Follow up studies revealed that these rocks exhibit a wide variety of calc-silicate minerals and, in addition, show divergent chemical compositions similar to those recorded for such special rock types as *rodingites*.

The term *rodingite* was first used by Marshall (1911) to describe numerous dykes of coarse-grained gabbro-like rocks penetrating serpentinites from the Roding River-Dun Mountain area near Nelson in New Zealand's South Island. These dykes were singled out for special attention because they possess a high percentage of lime as a result of the presence of conspicuous amounts of grossularite. Since then *rodingitic* rocks have been studied and described from numerous other localities in New Zealand (Grange, 1927; Turner, 1933; Hutton, 1943; Lauder, 1965; O'Brien and Rodgers, 1973), as well as elsewhere in the world. Without exception, the known *rodingite* occurrences are associated with serpentinitized ultramafic rocks, the latter frequently forming part of an Alpine-type ophiolite complex, or an ultramafic igneous complex, in which dunites, harzburgites, pyroxenites and gabbros are generally present. Numerous examples have been described from Pakistan (Bilgrami and Howie, 1960; Qaiser et al., 1970), New South Wales, Australia (Benson, 1914, 1926), Tasmania (Baker, 1958), Japan (Suzuki, 1940, 1952a, b, 1953), Scotland (Bloxam, 1954; Phemister, 1964), South Africa (de Waal, 1969), and the Alpine regions of Central Europe (Murgoci, 1900; Vuagnat, 1967; Dal Piaz, 1969).

Rodingite dykes are also commonly found in the ultramafic rocks of the Appalachian region in the Eastern Townships of Quebec (De, 1967, 1968, 1972; Riordon, 1957, 1975) as well as in serpentinitized ultramafic rocks extending along the west coast of North America from British Columbia south into Washington, Oregon, and California (Leech, 1949; Cater and Wells, 1953; Coleman, 1967, 1971).

Rodingitic rocks are also reported from an ultramafic and "coloured mélange" belt in North-eastern Iran (Davoudzadeh, 1972; Alberti et al., 1976) and have been dredged from the Mid-Atlantic Ridge (Aumento and Loubat, 1971; Honnorez and Kirst, 1975).

Rocks containing some of the diagnostic mineral assemblages found in *rodingites* (hydrogrossular, diopside) also include the anorthosites and pyroxenites of the Bushveld Igneous Complex in South Africa (Hall, 1924, 1932; Frankel, 1959). The anorthosites appear to be the only hosts to *rodingitic* rocks that are not influenced by the presence of serpentinitized ultramafic lithologies and give rise to the mineral known under the trade name of "South African Jade". This jade has been identified as hydrogrossular and represents a pseudomorphous replacement of anorthosite layers associated with chromitite bands (Tilley, 1957).

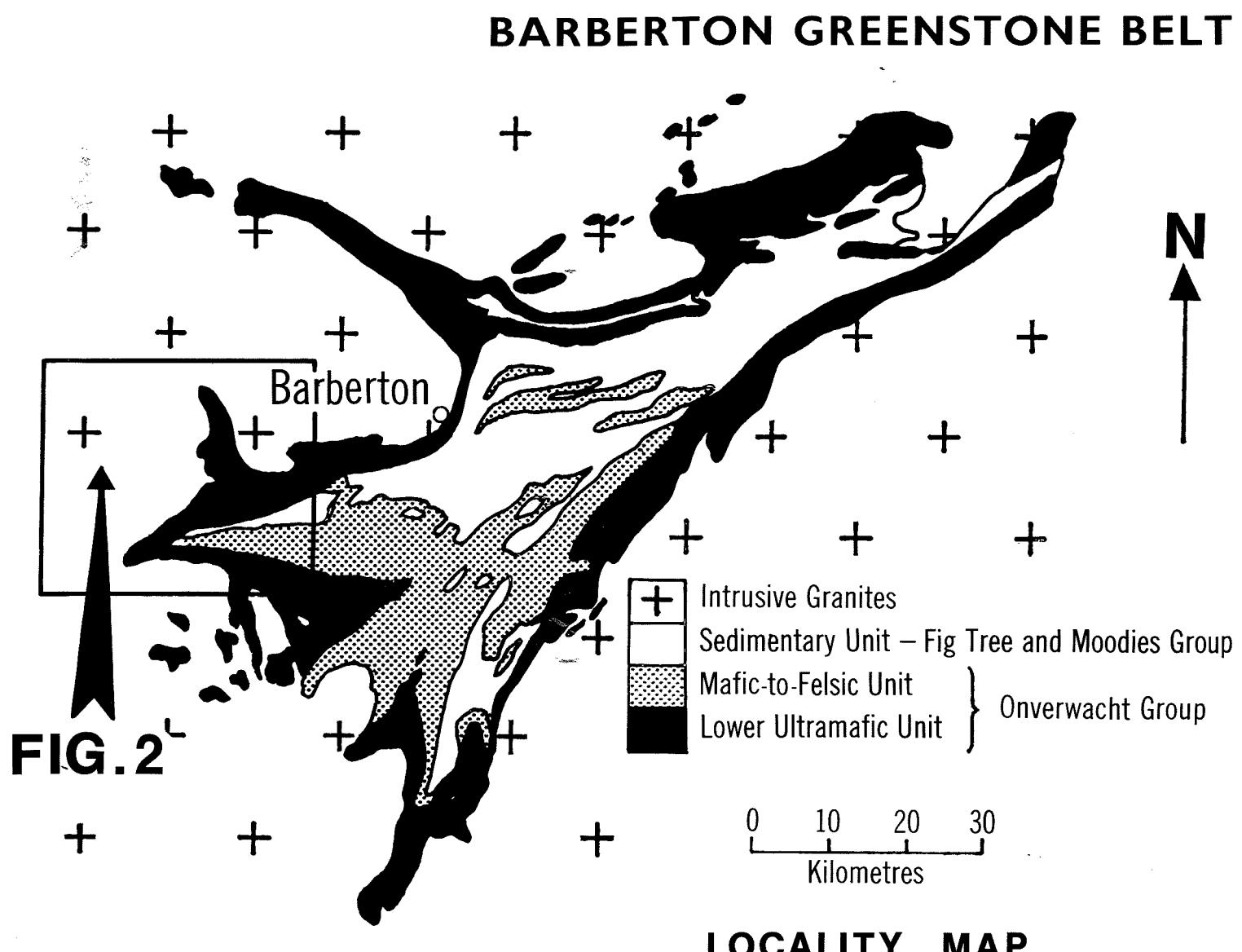
The majority of *rodingite* occurrences in the world are to be found in Phanerozoic orogenic belts where serpentinitized ultramafic rocks are common. Only one Archaean *rodingitic* occurrences has been reported, this being from the Eulaminna District, Mt. Margaret Goldfield, Western Australia, where Miles (1950) recognized the distinctive lime silicate minerals diopside and grossularite in garnetized gabbros which occur as tabular bodies surrounded by areas of serpentinitized peridotite. Detailed investigations led to the conclusion that the garnetized gabbros were similar to the *rodingites* of New Zealand and the grossularite, vesuvianite, and prehnite-bearing rocks found closely associated with serpentinites in the Great Serpentine Belt of New South Wales, and in several localities in Europe, Russia, and Canada, described by Murgoci (1900), Benson (1914, 1926), Graham (1917) and Arshinov and Merenkov (1930).

This paper is intended to draw attention to new occurrences of *rodingite* found in the Archaean ultramafic complexes of the Barberton greenstone belt and to compare and contrast these rocks with others reported in the literature. In addition to briefly outlining the geological setting of these new *rodingite* occurrences views on the nature and origin of *rodingitic* rocks in general will also be reviewed.

II. GENERAL GEOLOGY

More than 20 layered differentiated ultramafic complexes have been recognized in the Barberton greenstone belt, many of which contain economically significant deposits of chrysotile asbestos (Anhaeusser, 1969, 1975, 1976; Viljoen and Viljoen, 1969a; Robb, 1977). Most of the layered complexes are situated on the northwest flank of the greenstone belt where they occur as sills or discontinuous pods, the latter intruded penecontemporaneously with the mafic and ultramafic lavas that together make up the lowermost stratigraphy of the Onverwacht Group (the *Lower Ultramafic Unit*, as defined by Viljoen and Viljoen, 1969b).

While investigating the Stolzburg ultramafic body, located in the extreme southwestern portion of the Barberton greenstone belt (Figures 1 and 2), rocks possessing affinities with *rodingites* were



LOCALITY MAP

Figure 1 : General geological map of the Barberton greenstone belt showing the regional locality of the layered ultramafic complexes in which the rodingites occur.

found occurring either, as dykes cutting serpentinites or, as metasomatized gabbroic layers, the latter forming part of the stratigraphy of the differentiated ultramafic complex. Subsequent investigations by the writer, as well as M.G. Wuth (personal communication, 1978), showed that similar rodingitic rocks occur in the Hilversum-Sassenheim layered bodies located approximately 15 km southwest of Barberton. It thus appears likely that, as detailed investigations of the various layered ultramafic bodies proceed, further rodingite discoveries may be made.

The Stolzburg body occurs in the Nelshoogte Schist Belt which consists of a succession of basaltic lavas, interlayered with peridotitic lavas and a few minor siliceous schists and banded chert bands. Over 90 per cent of the rocks in the area consist of komatiitic or tholeiitic basalts, whereas extrusive peridotitic komatiites and altered felsic volcanics and chemical sediments make up the remainder of the succession. The Nelshoogte Schist Belt is bounded on the west and northeast by two diapiric granite plutons. The Kaap Valley Granite (Figure 2) consists of a hornblende-biotite tonalite gneiss and has yielded an U-Pb age of 3 310 m.y. The Nelshoogte Granite, by contrast, consists of a leuco-biotite tonalite or trondhjemite gneiss, and has an age of 3 220 m.y. (Oosthuyzen, 1970).

The intrusive granites were responsible for the development of the northwest protruding schist belt wedge, as well as for the production of various mafic and ultramafic schists, particularly near the greenstone-granite contact zones. Most of the rocks in the schist belt have been subjected to greenschist facies metamorphism but rocks close to the granite contacts show lower amphibolite metamorphic assemblage. In the south, where the schist belt is at its widest, well-preserved pillows and spherulites are still evident in the basalts. Abutting this area is the Stolzburg Ultramafic Complex which has suffered relatively little deformation and only low grade metamorphic alteration.

The Stolzburg body, which exceeds 16 km in length and averages one kilometre in width, is bounded on the northwest and southeast by two major faults (Figure 3). The vertical to subvertical dipping formations consist of a Lower Division, made up essentially of a cyclic succession of serpentized dunite and orthopyroxenite layers. The Upper Division, which is developed south and east of the Doyershoek asbestos mine (Figure 3) consists mainly of serpentized harzburgites and peridotites, the latter commonly associated with layers of gabbro or norite, and, in places, gabbroic to noritic anorthosites.

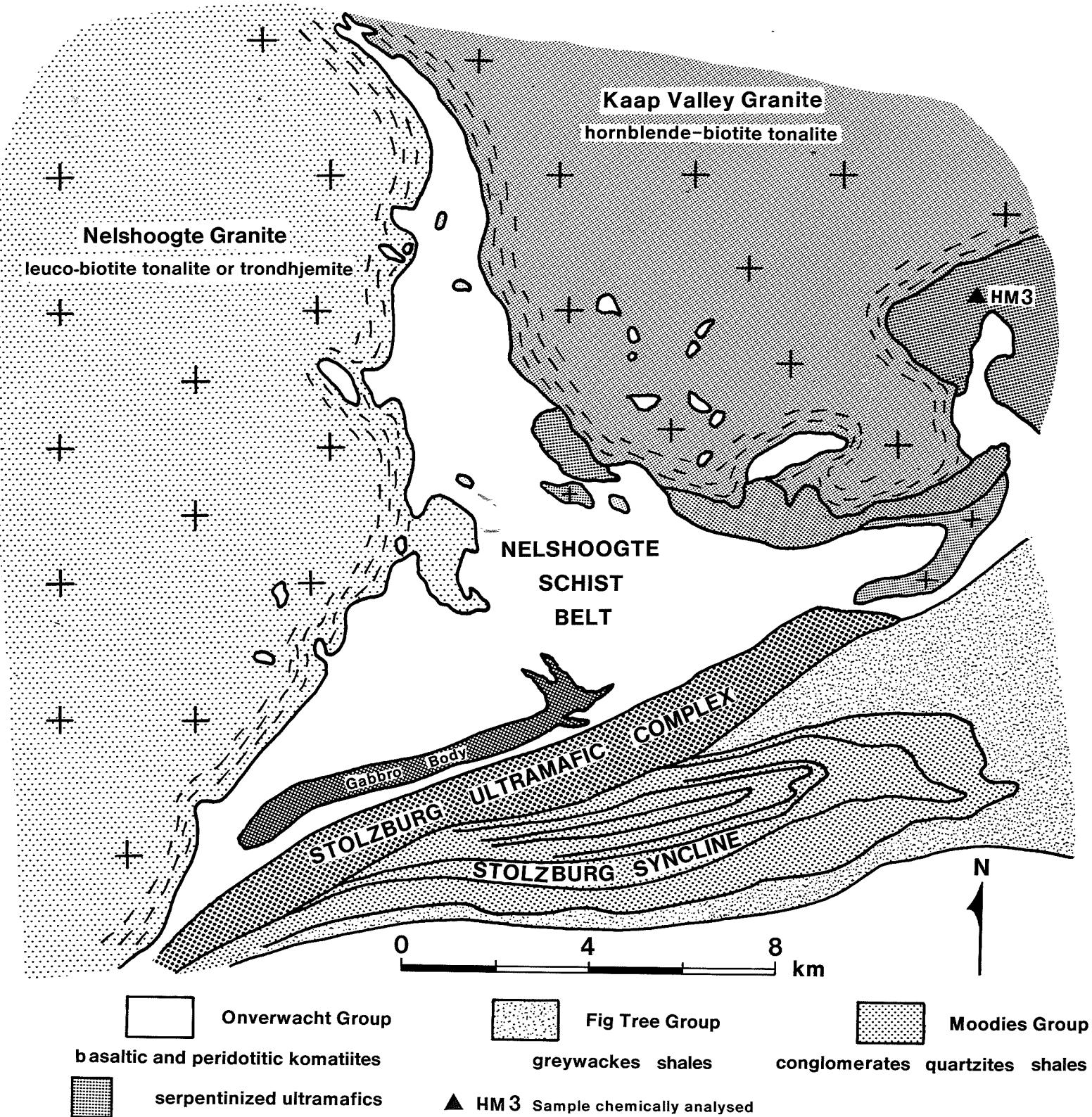


Figure 2 : General geological map of the Nelshoogte Schist Belt showing the regional setting of the Stolzburg Ultramafic Complex and the serpentized masses to the northeast.

In the central portion of the Complex, in the transitional zone between the Lower and Upper divisions, are rocks that have undergone lime metasomatism to form the rodingites that will be described more fully in a later section.

At least 12 cycles are present in the Dayershoek mine area, while in the Stolzburg and Sterkspruit mine areas to the southwest, only cycles of the Lower Division are present, the upper cycles being truncated by a fault cutting obliquely across the complex. As has been described by Anhaeusser (1976), the lower members of the layered sequence occur on the northwestern side of the body and consist of alternating serpentized dunites (olivine cumulates) and generally altered but, in places, remarkably fresh orthopyroxenite layers (enstatite, bronzite cumulates). The upper half, on the southeastern side of the body, consists mainly of serpentized harzburgites and peridotites (including

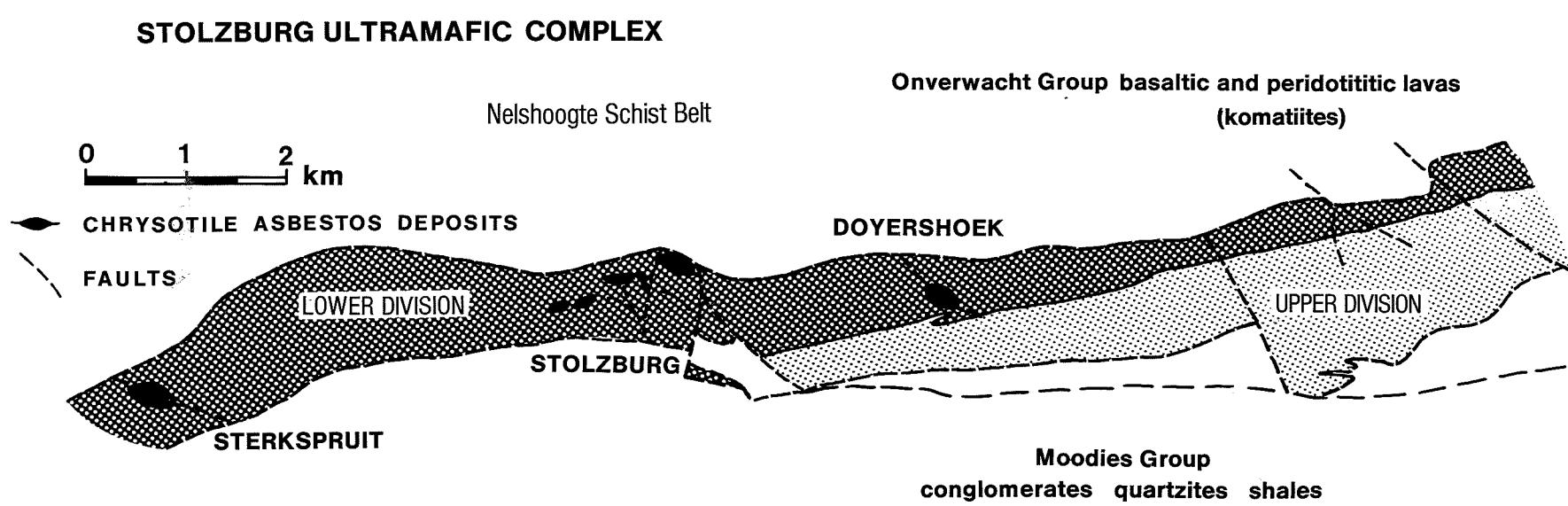


Figure 3 : Simplified geological map of the Stolzburg Ultramafic Complex showing the location of chrysotile asbestos deposits and the regional extent of the Lower and Upper divisions of the layered body.

Therzolites and wehrellites), pyroxenites (ortho and clinopyroxenite - websterite), and altered gabbros, norites, and anorthositic gabbros. Figure 4 provides a schematic representation of the layering and cyclical repetition of cumulate units from base to top across the Stolzburg body. It must be pointed

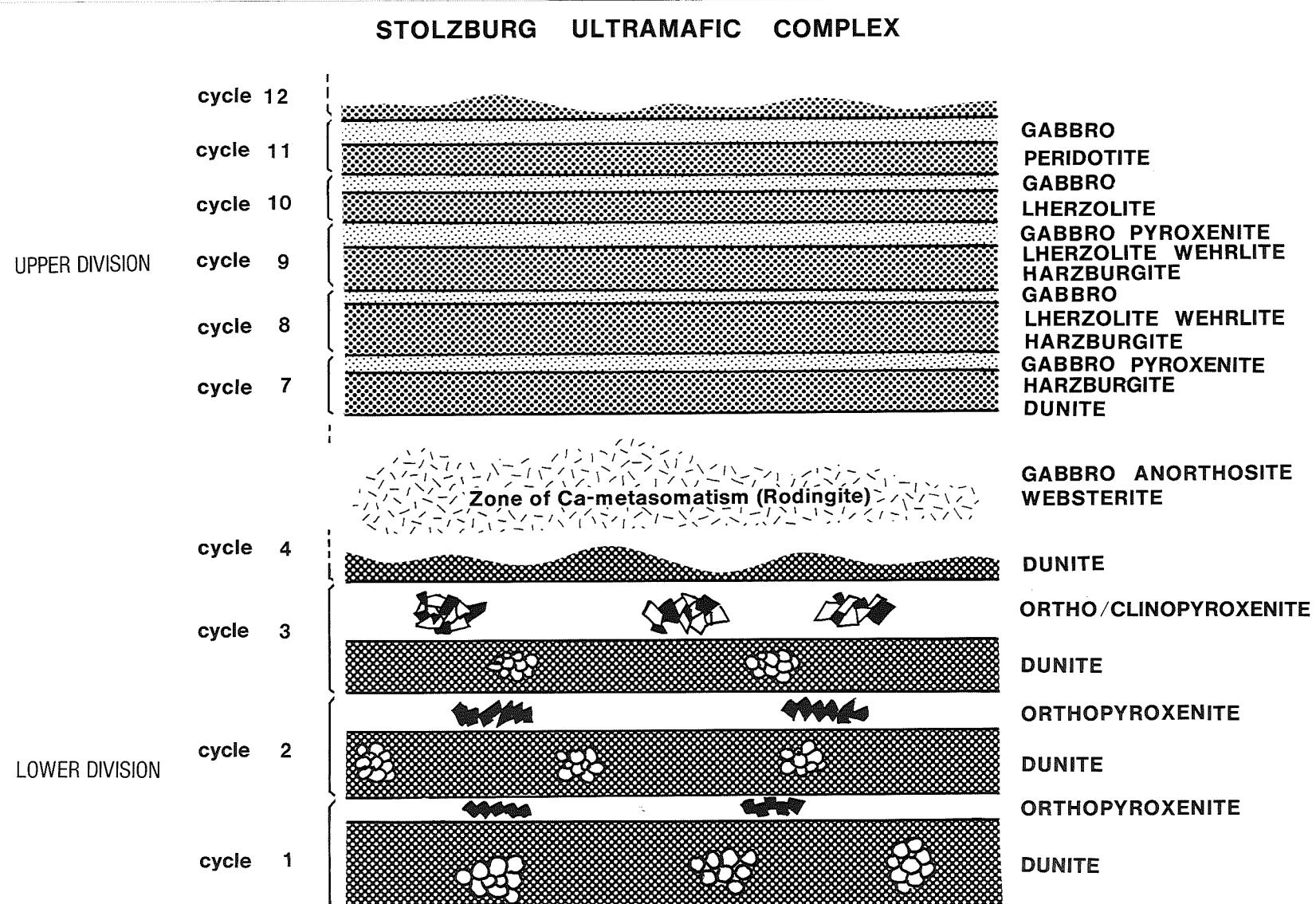


Figure 4 : Schematic section showing the nature of the cumulate assemblages and the cyclical repetition of layering in the Lower and Upper divisions of the Stolzburg Ultramafic Complex. Attention is drawn to the zone of rodingite development located at the boundary between the two divisions.

out, however, that there are upwards of seven cycles (of the type found in the Lower Division), in the region between the Sterkspruit and Stolzburg mines (Figure 3). Similarly, there are approximately 10 cycles (of the type found in the Upper Division) in the region east and northeast of the Doyershoek mine.

The zone of calcium metasomatism, depicted in Figure 4, occurs in the region where mono-mineralic cumulate phases (dunites, enstatites, bronzitites) give way to rocks containing two or more mineral phases (harzburgites, lherzolites, wehrlites, websterites, diopsidites, gabbros). In the field the zone of prominent calcium enrichment or rodingite development is located in the vicinity of the Doyershoek mine and in the following section a more detailed account of the geology of this region is given.

III. GEOLOGY OF THE STOLZBURG COMPLEX IN THE VICINITY OF THE RODINGITE OCCURRENCES

Figure 5 provides a more detailed geological map of part of the Stolzburg layered ultramafic body in the vicinity of the rodingite occurrences. As mentioned previously, the attitude of the various layers comprising the complex are either vertical or steeply dipping ($70-90^\circ$) to the northwest. Three prominent dunite units and two orthopyroxenite units constitute the Lower Division of the Stolzburg

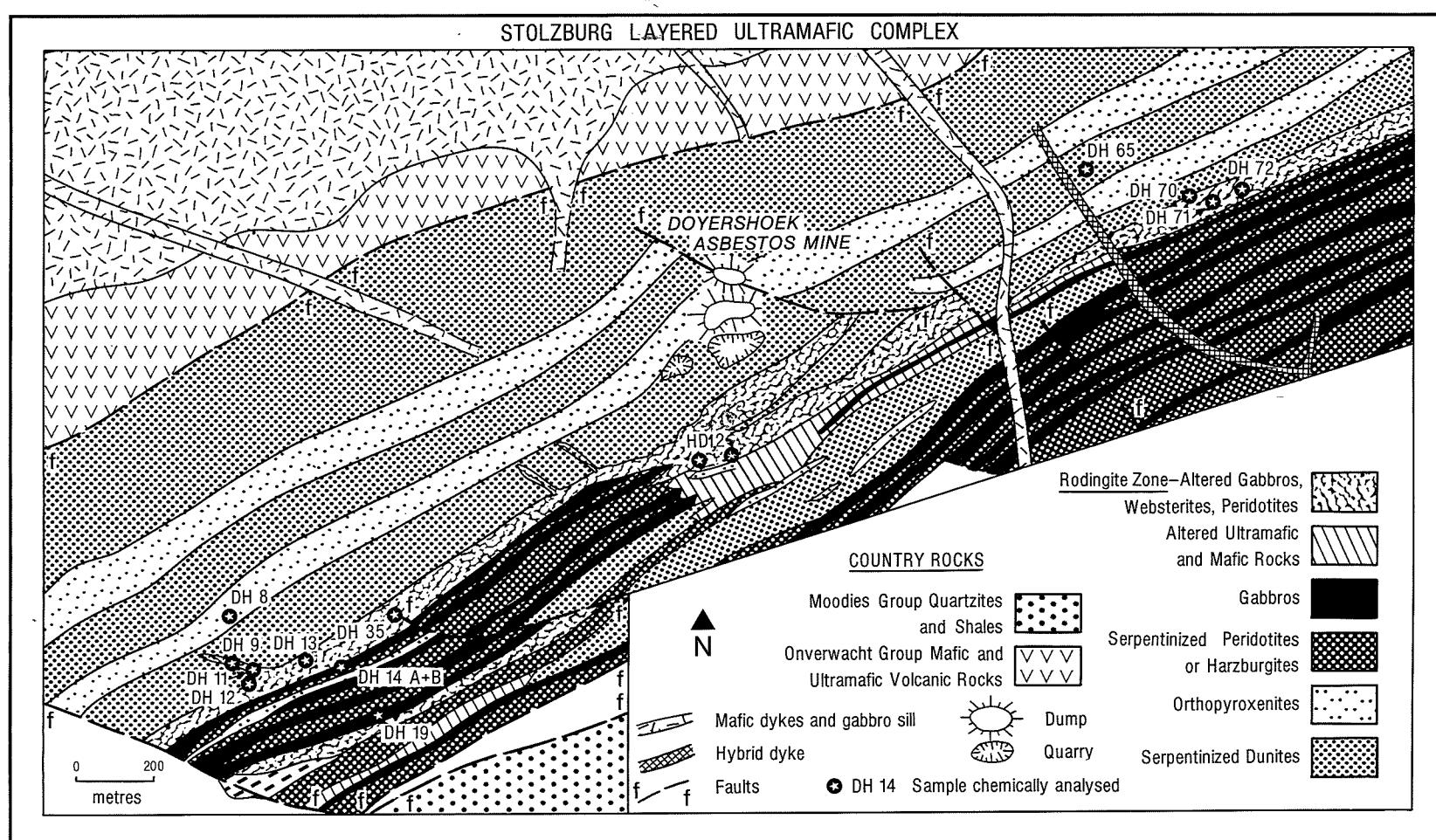


Figure 5 : Detailed geological map of part of the Stolzburg Ultramafic Complex in the vicinity of the Doyershoek asbestos mine. The layered complex, which is vertical or steeply dipping to the northwest, shows a cyclically repetitive sequence of dunites, orthopyroxenites, harzburgites, websterites, and gabbroic rocks younging to the southeast. The Rodingite Zone and rodingite dykes are located in the centre of the body.

body southwest and northeast of the Doyershoek asbestos mine. The excellent exposure and well-layered nature of the region depicted in Figure 5 can be seen in Plate 1A which shows part of the Stolzburg body as viewed from the Stolzburg asbestos mine. The orthopyroxenite layers show up as more resistant bands covered by bushy vegetation whereas the interlayered dunites are less resistant and form smoother, grass-covered, expanses between the pyroxenites.

The dunites are totally serpentinized but the original cumulate texture is preserved by antigorite pseudomorphous after large olivine crystals (some measure up to 1 cm in diameter). The

altered dunites consist mainly of antigorite, serpophite, iddingsite, chlorite, and magnetite. In some specimens accessory intercumulus orthopyroxene may be present, the latter generally altered to bastite. Chemical analyses of two typical serpentized dunite samples from northeast of the Doyershoek asbestos workings are given in Table 1, columns 1 and 2.

The orthopyroxenites in the succession are composed almost entirely of enstatite or bronzite and show variable degrees of alteration to antigorite (bastite) or talc. The rocks are bluish-green or black in colour on fresh surfaces but are characteristically reddish-brown on weathered surfaces. The coarse-grained cumulate texture of the rocks is everywhere apparent, even where talc totally pseudo-morphs the orthopyroxene. In thin sections the pyroxenes commonly exhibit schiller structure, and magnetite may be encountered as an accessory mineral. An analysis of a partly altered orthopyroxenite from southwest of Doyershoek mine is listed in Table 1, column 4.

The *Rodingite Zone*, separating the Lower Division from the Upper Division in Figure 5, consists of numerous rock types, including peridotites, pyroxenites, and gabbros. The exposure in the zone is, unfortunately, very variable and this, coupled with the fact that most of the rocks are altered, makes it difficult to produce a map portraying all the components present in the area. In addition, it appears that a number of thin pyroxenite and harzburgite layers occur as lenses in the zone together with a variety of gabbroic and anorthositic rocks.

In the southwestern corner of Figure 5, the Rodingite Zone contains lenses and pods of serpentized harzburgite and altered websterite. The serpentized harzburgite (sample DH35) consists of outcrops displaying coarse nodular aggregates of olivine and orthopyroxene (nodules average approximately 4 cm in diameter). The olivine and enstatite in the nodules are only partly altered but in the areas surrounding the nodules the rocks are totally altered to antigorite, chrysotile, chlorite, bastite, and talc. Iron, liberated from the serpentized olivines, occur as magnetite. Some samples from the same outcrop area contain minor amounts of clinopyroxene (diopside, diallage) and the rocks approach lherzolite or wehrlite in composition. Table 1, column 3, provides an analysis of a serpentized harzburgite from this locality.

In the same general area sample DH12 (Figure 5 and Table 1, column 5) represents a partly altered websterite consisting almost entirely of diopside together with laths or blades of tremolite and chlorite (Plate 2E), and accessory amounts of ilmenite and leucoxene. In addition, there is some grossular garnet, the latter partly altered to chlorite. The pyroxenite appears to be gradational into altered gabbroic rocks in which the first signs of plagioclase appear.

The Upper Division of the Stolzburg Complex comprises rapidly alternating cycles of ultramafic and gabbroic rock types. The ultramafic components, as depicted schematically in Figure 4, consist mainly of serpentized harzburgites but, from place to place, dunites, lherzolites, and wehrellites, may be encountered. The textures of the rocks in the upper portions of the layered body are finer-grained, and the cumulate textures, so common in the Lower Division, are not always apparent.

The gabbroic rocks in the upper layers of the complex vary from coarse, almost pegmatoid-like exposures, to mottled gabbros having a medium-to-fine-grained texture. In some areas the gabbros have abundant euhedral plagioclase laths and in places there are blotchy patches or vein-like dykelets of anorthositic or anorthositic gabbro. The textural variations from one outcrop to the next are extremely variable and some of the gabbros in the uppermost cycles, particularly east of the Doyershoek mine, could easily be mistaken for basaltic lavas due to the fine-grained character of the rocks.

The variability of the gabbros, or pyroxenitic gabbros, as recorded in the field, are also reflected in their chemistry (Table 1, columns 6-9). The gabbroic rocks show a spread in composition which almost precisely coincides with the three-fold subdivision of the basaltic komatiite suite reported from the Lower Ultramafic Unit in the Onverwacht Group type locality in the Komati River Valley. Here, Viljoen and Viljoen (1969b) distinguished, on the basis of the variability of magnesian contents, basaltic komatiites of the Barberton-type (~ 10 per cent MgO), the Badplaas-type (~ 15 per cent MgO), and the Geluk-type (~ 20 per cent MgO).

In addition to the above three representatives, the gabbroic rocks of the Stolzburg Complex also display compositions similar to tholeiitic basalts (sample DH19, Table 1, column 9).

Petrologically the gabbroic or noritic rocks in the Stolzburg body contain variable amounts of pyroxene (mainly diopside), and plagioclase (albite, oligoclase). The pyroxene is generally uralitized to tremolite-actinolite and the plagioclase is commonly saussuritized or sericitized to epidote, clinzoisite, or sericite (Plate 2F). Accessory minerals found in these rocks include magnetite, ilmenite, and chlorite. Within the Rodingite Zone garnetization of the gabbros has occurred and hydrogrossular and chlorite alteration products are commonly encountered (sample DH72).

Plagioclase-rich gabbroic anorthosites are developed in places in the upper parts of the layered body as well as in the area immediately south of the Doyershoek mine (Figure 5). Samples from the Rodingite Zone show abundant plagioclase and diopside, the minerals being either segregated into layers (sample HD1, Plate 2D), or forming an interlocking or decussate texture. Some of the pyroxene in the rocks has been uralitized to tremolite or actinolite and the plagioclase is saussuritized to epidote and zoisite. Accessory components in the rocks include sphene, magnetite, and ilmenite. The

TABLE I
Chemical Analyses of Various Rock Types Comprising the
Stolzburg Layered Ultramafic Complex Found in the Vicinity of the
Main Zone of Rodingite Development

	1	2	3	4	5	6	7	8	9	10	11
	DH65 [†]	DH70 [†]	DH35*	DH 8 [†]	DH12*	DH72 [†]	DH14A [†]	DH14B [†]	DH19 [†]	HD 2*	HD 1*
SiO ₂	38,99	39,28	39,60	52,14	43,60	48,81	51,97	52,88	53,33	56,90	62,90
TiO ₂	0,11	0,11	0,10	0,11	0,93	0,17	0,26	0,30	0,48	0,54	0,50
Al ₂ O ₃	2,40	3,01	2,32	2,03	6,25	4,99	6,23	11,09	12,27	13,24	14,52
Fe ₂ O ₃	6,26	4,46	6,49	1,05	1,80	1,03	0,84	1,38	1,12	1,62	0,49
FeO	1,07	3,15	2,87	6,89	11,11	6,63	7,67	5,48	9,17	3,22	3,79
MnO	0,12	0,13	0,15	0,18	0,22	0,11	0,14	0,11	0,15	0,09	0,05
MgO	37,90	36,12	36,60	28,74	17,03	23,16	16,59	12,57	8,77	6,64	4,79
CaO	0,04	1,02	1,64	2,28	14,42	10,13	11,23	10,39	8,34	9,95	4,60
Na ₂ O	0,03	0,03	0,11	0,04	0,21	0,04	1,16	2,96	3,07	5,07	6,67
K ₂ O	0,01	0,01	0,02	0,27	0,04	0,05	0,39	0,22	0,71	0,15	0,15
P ₂ O ₅	0,03	0,03	0,03	0,04	0,15	0,06	0,06	0,06	0,09	0,04	0,04
H ₂ O ⁺	12,00	11,21	10,08	5,52	3,94	4,18	2,57	2,25	2,22	1,41	0,90
H ₂ O ⁻	0,43	0,24	0,37	0,06	0,19	0,22	0,08	0,11	0,08	0,28	0,09
CO ₂	0,16	0,18	0,11	0,10	0,02	0,08	0,51	0,08	0,12	0,18	0,04
Cr ₂ O ₃	0,12	0,83	0,50	0,48	0,06	0,27	0,27	0,10	0,08	0,01	0,08
Total	99,67	99,81	100,99	99,93	99,97	99,93	99,97	99,82	100,00	99,34	99,61

Analysts : * National Institute for Metallurgy, Johannesburg.
† National Institute for Metallurgy, Johannesburg and Durham University, England.

- Column 1. Serpentinized dunite
2. Serpentinized dunite
3. Serpentinized harzburgite
4. Partly altered orthopyroxenite (enstatite-bronzite)
5. Websterite (clinopyroxenite)
6. Garnetized gabbro-norite
7. Uralitized websterite
8. Uralitized gabbro
9. Uralitized gabbro
10. Saussuritized gabbro
11. Albitized gabbro

plagioclase in some specimens, like that of HD1, occurs as a microcrystalline mosaic in layers between the diopside-rich partings. Chemical analyses of the gabbroic anorthosites (Table 1, columns 10 and 11) show that the rocks are enriched in Na_2O , and probably represent the products of albitionization of pre-existing feldspar of more calcic composition (Turner and Verhoogen, 1960).

IV. STOLZBURG RODINGITE OCCURRENCES

Although rodingite veins or dykes have been observed in diamond drill core from the underground workings of the Stolzburg asbestos deposit it was not possible for the writer to gain access to the occurrences as the mine has been closed for over twenty years. The Stolzburg rodingites here referred to will be largely confined to a description of the occurrences found within or adjacent to the Rodingite Zone shown in Figure 5.

A. Field Occurrence

The rodingites located in the central part of the Stolzburg layered body occur either in the form of dykes or as irregular pods or replacement bodies closely associated with, and gradational into, the gabbroic rocks found in the region transitional between the Lower and Upper divisions of the layered complex.

The rodingite dykes encountered in the area all penetrate into the footwall serpentized dunite unit adjacent to the Rodingite Zone. In the field the dykes are distinctive in that they generally outcrop positively in relation to the surrounding serpentinites (Plate 1 B-E) and are easily identified owing to their characteristic buff, or pale fleshy pink coloured weathered surfaces. Some rodingite dykes may also be greenish-white, greenish-grey, yellowish-green or even cream-coloured. In places the fresh rock can be milky white or greyish-white (hence the term "white dykes" referred to by De, 1972). These colour characteristics are also reported from many rodingite occurrences around the world (Miles, 1950; Suzuki, 1953; Bilgrami and Howie, 1960; Alberti et al., 1976).

The rodingite dykes in the Stolzburg body range in width from approximately 5 m down to dykelets or veins only centimetres wide. Some dykes display fine-grained chill margins (Plate 2A) while others show fine banding or layering orientated parallel to the dyke margins in contact with the surrounding serpentinite. This fine banding is illustrated in Plate 2B and takes the form of alternating layers of hydrogrossular (hibschite) and layers of generally amorphous material, the composition of which could not be satisfactorily determined either optically or by X-ray methods. Some of the material in the layers consists of uralitized pyroxene (diopside, diallage), together with chlorite, nephrite, and fine magnetite dust particles. Small round specks of what appears to be a second variety of garnet also occurs in the amorphous layers as well as in the extremely fine-grained part of the dyke, well-removed from the contacts. As opposed to the pale honey yellow hibschite, found in the contact layers, the small round garnets are colourless and are partly or wholly altered to chlorite.

Most of the rodingites described in the literature contain only one garnet - hydrogrossular. Duffield and Beeson (1973) were the first to report a two-garnet rodingite from Amador County, California. The two garnets, found by accident from X-ray diffractometer analysis, consisted of hydrogrossular and (hydro ?) grossular-andradite - both varieties occurring in roughly equal abundance. It was concluded that both garnets grew simultaneously in one general period of metasomatism and that their compositions reflected the unequal distribution of major elements, principally iron and aluminium, in the original unaltered rock which happened to be a mafic dyke with abundant plagioclase laths.

The Stolzburg rodingite dykes display a variety of colours and textures but typical examples occur as hard, dense, massive, fine-grained rocks. As has been found by numerous investigators, few of the mineral constituents can be identified with the unaided eye. In some cases only the small round garnets, referred to earlier, are evident in an otherwise extremely dense, compact matrix.

In the Rodingite Zone the variations encountered in texture and colour are, to a large extent, determined by the nature of the original rock types found in the region. Medium-to-coarse-grained uralitized gabbros outcrop most prominently in the zone and appear also to be most influenced by the lime-metasomatism affecting the region. Unlike the dykes, the gabbroic and pyroxenitic rocks in the Rodingite Zone retain part of their original mineralogy and texture and it is possible to say, without hesitation, that rodingitization (garnetization) has been superimposed on the rocks in the area.

B. Petrography of the Rodingites

Thin section examination of the rodingitic rocks from the Stolzburg body revealed a great variety of calc-silicate minerals. Due to the extremely fine-grained, sometimes amorphous, nature of the rocks, mineral identification often had to be accomplished using X-ray powder patterns.

Almost without exception the rodingitic rocks examined all contained garnet. As mentioned earlier two garnet varieties were noted under the microscope - the one occurring as clear, round grains sometimes approximately 1 mm in diameter but generally being less than half this size. These garnets

are mainly altered and extremely difficult to investigate. Several X-ray attempts could not define precisely their composition. The other garnet present in the rodingite occurs as anhedral, highly irregular (even amorphous), masses filling all available spaces between larger, subhedral to euhedral crystals of other minerals that may be present in the rocks. X-ray investigations showed that this garnet, which may be colourless, turbid, or even pale honey yellow, was either hydrogrossular or hibschite. According to Hutton (1943), and Pistorius and Kennedy (1960) there is a continuous solid-solution series from grossularite ($3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot3\text{SiO}_2$), through hydrogrossularite, to hibschite ($3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot2\text{SiO}_2\cdot2\text{H}_2\text{O}$), and it appears that in the Stolzburg body at least two members of the solid-solution series of hydrogarnets may be present. More detailed mineralogical studies might even reveal several components of the ugrandite garnet series as defined by Winchell (1958), and even the (hydro?) grossular-andradite garnets like those found in the Californian rodingites by Duffield and Beeson (1973).

The hydrogarnets in the Stolzburg body are often closely associated with vesuvianite (idocrase) and the two minerals are sometimes difficult to distinguish optically. Although small crystals of the hydrogarnet are isotropic, weak birefringence is rather characteristic of the ugrandite series (Deer et al., 1962), as well as vesuvianite, which is known to have a structure closely related to that of grossular garnet.

Although difficult to distinguish at times, the weakly birefringent garnets show signs of zoning, and sector twinning is frequently observed (Plate 2C). The vesuvianite, which is colourless, commonly displays anomalous brown interference colours which help in the optical identification of the two minerals.

Diopside is a prominent constituent of the rodingitic rocks. Much of this mineral occurs as an original constituent, particularly in the websterites and diopsidites, but some may be of secondary origin. Diopside is also present in the gabbroic and anorthositic gabbroic rocks (Plate 2D) but is commonly intermingled with small amounts of tremolite and chlorite which are probably secondary (uralitized) alteration products of the pyroxene.

Zoisite and epidote are two further minerals that are often encountered in the rodingites - particularly the gabbroic varieties where plagioclase was initially relatively abundant. In some rodingites, (e.g. sample HM3, from the Hilversum layered body northeast of Stolzburg, Figure 2 and Table 2) the rock, which has a yellowish-green to white colour on fresh surfaces, consists almost entirely of zoisite or clinozoisite, together with lesser amounts of diopside, tremolite, epidote, and sphene. Saussuritization of the plagioclase feldspars is largely responsible for the zoisite and epidote developed in most of the gabbros (Plate 2F), but some may also have been introduced into these rocks as a result of Ca-metasomatism.

The tough, compact, variety of tremolite-actinolite, known as nephrite (jade in part), was recorded in some of the rodingite dykes. The mineral, which in some cases displays spectacular sprays of interfelted fibrous crystalline aggregates (Sample DH9, Figure 5), occurs together with small, round, hydrogarnet crystals, the latter largely altered to chlorite. A second sample (DH11), of seemingly identical rock, and possessing the same grey-green colour, fine texture, density, and small round garnets studded throughout, was collected several metres away within the same dyke (Figure 5). Surprisingly, the nephrite, which was so prominent in the one sample, was totally absent in the second. Instead, sample DH11 consisted of diopside (~ 25%), vesuvianite (~ 25%) and honey brown hydrogrossular (~ 45%). Accessory components included the small round garnets, chlorite, and veins of prehnite. From these observations it can only be concluded that the nephrite, which predominates in sample DH9, must have been derived from the alteration of diopside, vesuvianite, and hydrogrossular, as none of these minerals are apparent in the rock.

Other minerals encountered in the rodingites include prehnite, plagioclase, magnetite, and sphene. The prehnite occurs mainly in veinlets and as small aggregates, in some of which characteristic bow-tie structures were noted. The plagioclase is commonly saussuritized or sericitized but where the composition could be established it was found to be either albite or oligoclase. Accessory components include sphene and magnetite, the latter occurring mainly as minute dust-like particles or aggregates, particularly in the banded contact zones in the rodingite dykes.

C. Chemistry of the Rodingites

Chemical analyses of five rodingitic rocks from the Barberton greenstone belt are given in Table 2, columns 1-5. Four samples are from the Stolzburg layered complex (Figure 5) whereas the remaining sample (HM3) is from the Hilversum ultramafic body northeast of Stolzburg (Figure 2). Also listed in Table 2, for comparison, are analyses of rodingites from numerous localities around the world.

The rodingites, being generally accepted as largely of replacement origin (Ca-metasomatized rocks, see later), demonstrate a wide range of compositions. Despite the variations, however, the rocks show the same general tendency of possessing extremely high CaO values, relatively high Al_2O_3 and generally low SiO_2 and MgO contents.

The main point of difference between the Stolzburg rodingites and those from other localities centres around their generally lower alumina contents. Exceptions are the Archaean garnetized gabbros from Western Australia (Table 2, columns 9 and 10) which also possess comparatively low amounts of

TABLE 2
Chemical Analyses of Lime-rich Rodingitic Rocks from the Barberton Mountain Land,
South Africa, Compared with Similar Rock Types from Elsewhere in the World

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
	DH 9*	DH11*	DH13†	DH71‡	HM 3*				2/3144	2/3285	A	B	J-1	1	RDF	A	121A	
SiO ₂	40,50	39,10	43,20	46,68	45,90	33,95	33,42	40,63	45,31	40,98	38,43	40,58	36,36	37,04	35,60	38,04	41,90	
TiO ₂	0,91	0,96	0,58	0,78	0,29	0,42	0,30	-	0,46	1,01	tr	tr	-	0,58	0,65	0,82	0,08	
Al ₂ O ₃	13,10	13,20	11,50	7,14	17,60	19,91	14,34	17,67	7,49	12,77	22,06	15,03	25,64	15,15	10,45	15,07	17,80	
Fe ₂ O ₃	3,66	6,19	3,14	2,29	4,58‡	1,28	10,32	0,96	1,02	1,10	1,70	3,56	0,27	1,81	8,61	1,78	<0,10	
FeO	6,70	3,70	3,30	2,39	-	6,98	2,44	1,48	5,12	4,06	1,95	3,90	0,50	6,98	1,29	3,02	1,60	
MnO	0,11	0,14	0,14	0,19	Ni1	0,28	0,75	0,28	0,31	0,16	-	-	-	0,13	0,08	0,21	0,31	
MgO	4,60	5,10	7,43	7,94	6,45	5,23	4,66	6,07	14,66	7,31	2,41	4,45	3,05	6,70	4,20	9,62	4,00	
CaO	27,90	28,80	29,40	30,75	22,20	26,95	29,40	31,04	22,70	29,40	28,56	26,62	32,50	27,35	33,10	25,84	28,10	
Na ₂ O	0,05	0,20	0,01	0,04	0,10	0,01	0,02	0,15	0,14	0,13	0,04	-	1,35	1,51	0,49	0,18	0,10	
K ₂ O	0,03	0,06	0,01	0,01	0,02						0,04	0,03	0,34	0,26	0,14	0,02	0,04	0,10
P ₂ O ₅	0,17	0,19	0,11	0,15	0,02	Ni1	Ni1	-	0,08	0,12	-	-	-	0,05	0,09	0,17	0,24	0,06
H ₂ O ⁺	1,90	2,00	1,56	1,37	-	4,85	3,63	1,20	2,65	2,68	2,50	3,56	1,03	4,04	4,98	4,19	3,50	
H ₂ O ⁻	0,04	Ni1	0,08	0,12	-	-	-	-	0,24	0,31	0,10	0,50	0,04	0,21	-	1,15	-	
CO ₂	-	0,05	0,06	0,09	-	Ni1	Ni1	-	0,06	0,07	-	-	-	-	-	Ni1	<0,10	
L.O.I.	-	-	-	-	2,24	-	-	-	-	-	-	-	-	-	-	-	-	
Total	99,67	99,69	100,52	99,94	99,40	100,00	99,40	99,54	100,54	100,09	99,40	99,97	100,13	100,28	99,13	100,20	97,60	

† Total Fe as Fe₂O₃

Analysts : * Bergström and Bakker; † National Institute for Metallurgy, Johannesburg; ‡ National Institute for Metallurgy, Johannesburg and Durham University, England.

Columns 1 - 4. Rodingites, Stolzburg-Doyershoek area, Barberton Mountain Land.

5. Diopside-zoisite 'rodingite', Hilversum area, Barberton Mountain Land.

6. Fine-grained rodingite from near Dun Mountain, Nelson, New Zealand (Marshall, 1911).

7. Dense rodingite, Long Gully, Lee River, Nelson, New Zealand (Marshall, 1911).

8. Rodingite, Roding River, Nelson, New Zealand (Marshall, 1911).

9 - 10. Garnetized gabbros, Eulamina Siding, Mt. Margaret Goldfield, Western Australia (Miles, 1950).

11 - 12. Rodingites, central Hokkaido, Japan (Suzuki, 1953).

13. Impure grossular rock (rodingite), Naranji Sar, Malakand, West Pakistan (Qaiser et al., 1970).

14. Fine-grained rodingite, Hindubagh, Pakistan (Bilgrami and Howie, 1960).

15. Garnet-rich rodingite, Northeastern Iran (Alberti et al., 1976).

16. Rodingitic garnetized gabbro, Byne Hill, Ayrshire, Scotland (Bloxam, 1954).

17. Rodingitic rock, British Canadian mine, Black Lake, Quebec, Canada (De, 1972).

alumina. A possible explanation may lie in the fact that the Stolzburg and Eulaminna rodingites appear to possess a relative abundance of diopsidic pyroxene (some uralitized to tremolite). Both these minerals have very little or no Al in their crystal lattice whereas the other minerals commonly encountered in the rodingites mainly reflect a wide range of calcium-aluminium silicates (Table 3).

TABLE 3
PRINCIPAL CALC-SILICATE MINERALS FOUND IN,
OR CONTRIBUTING TO, THE DEVELOPMENT OF RODINGITES

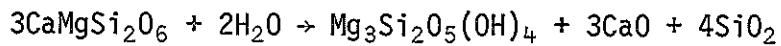
<u>Mineral</u>	<u>Chemical Formula</u>
Andradite	$\text{Ca}_3(\text{Fe}^{+3},\text{Ti})_2\text{Si}_3\text{O}_{12}$
Anorthite	$\text{CaAl}_2\text{Si}_2\text{O}_8$
Diopside	$\text{Ca}(\text{Mg},\text{Fe})(\text{Si}_2\text{O}_6)$
Epidote	$\text{Ca}_2\text{Fe}^{+3}\text{Al}_2\text{O}\cdot\text{OH}(\text{Si}_2\text{O}_7)(\text{SiO}_4)$
Grossular	$\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}$
Hibschite	$3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2\cdot 2\text{H}_2\text{O}$
Hydrogrossular	$\text{Ca}_3\text{Al}_2\text{Si}_2\text{O}_8(\text{SiO}_4)_{1-m}(\text{OH})_{4m}$
Jurupaite	$\text{H}_2(\text{Ca},\text{Mg})_2\text{Si}_2\text{O}_7$
Lawsonite	$\text{H}_4\text{CaAl}_2\text{Si}_2\text{O}_{10}$
Nephrite	$\text{Ca}_2(\text{Mg},\text{Fe})_5(\text{OH})_2(\text{Si}_4\text{O}_{11})_2$
Pectolite	$\text{Ca}_2\text{NaH}(\text{SiO}_3)_3$
Prehnite	$\text{Ca}_2\text{Al}(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$
Scapolite (meionite)	$\text{Ca}_4(\text{Al}_6\text{Si}_6\text{O}_{24})\text{CO}_3$
Tremolite-actinolite	$\text{Ca}_2(\text{Mg},\text{Fe}^{+2})_5(\text{Si}_8\text{O}_{22})(\text{OH},\text{F})_2$
Vesuvianite	$\text{Ca}_{10}(\text{Mg},\text{Fe})_2\text{Al}_4(\text{Si}_2\text{O}_7)_2(\text{SiO}_4)_5(\text{OH},\text{F})_4$
Wollastonite	CaSiO_3
Xonotlite	$5\text{CaSiO}_3\cdot\text{H}_2\text{O}$
Zoisite-clinozoisite	$\text{Ca}_2\text{Al}\cdot\text{Al}_2\text{O}\cdot\text{OH}(\text{Si}_2\text{O}_7)(\text{SiO}_4)$

Assuming for the moment that the original rocks to have been converted to rodingites in the Stolzburg body consisted mainly of gabbroic or pyroxenitic gabbroic rocks, similar in composition to those listed in Table 1 (columns 5-9), it is evident that the content of CaO in them ranges between 8-15 per cent. The overall change in composition, from rocks of this nature, to rodingites, can be seen to involve a considerable increase in calcium and a proportional decrease in most other components. This decrease is particularly evident with respect to SiO_2 , MgO , and the alkali elements. Al_2O_3 and, to a lesser extent, P_2O_5 do, however, show slight increases. Although no phosphatic mineral was noted in the rodingites it is possible that some cryptocrystalline colophane or dahlite (both weakly birefringent or isotropic) may be interspersed with the equally poorly birefringent, amorphous hydrogrossular-vesuvianite component of the rocks.

V. ORIGIN OF RODINGITES

In 1911 Marshall found numerous dykes of coarse-grained gabbro-like rocks penetrating serpentinites of the Dun Mountain massif in the upper reaches of the Roding River. He called these 'rodingite' because they differed from the gabbro in having a high percentage of lime as a result of the presence of large amounts of grossularite. Lauder (1965) redefined rodingite to include all leucocratic vein and dyke rocks in ultrabasic terranes that contain anomalous amounts of grossular, diopside, prehnite, vesuvianite and, perhaps, other minerals. O'Brien and Rodgers (1973) felt that because considerable mineralogical variations exist in rodingites the earlier definitions were too restrictive. They proposed extending the definition to include "any metasomatic rock, of basic or ultrabasic parentage, consisting of clinopyroxene, which may be derived from the parent, garnet derived wholly by metasomatic process, and possibly other metasomatic products such as prehnite, serpentine, chlorite, and xonotlite".

It can be seen from this last definition that O'Brien and Rodgers (1973) regarded a metasomatic origin as axiomatic to rodingite petrogenesis. Previously a number of hypotheses had been advanced beginning with Marshall (1911), who considered that the grossular-bearing rocks in the Roding River area had resulted from magmatic differentiation. Benson (1926), Grange (1927), and Turner (1933), postulated that the rodingites had formed by the garnetization of gabbroic rocks, by concentrated magmatic waters acting at high pressures. As stated by Turner and Verhoogen (1960), some writers regard the magmatic lime as having been concentrated in residual solutions left after crystallization of the ultrabasic "magma", while still others envisage it as having been set free during serpentinization of diopsidic pyroxene in the ultramafic rocks (Grange, 1927; Arshinov and Merenkov, 1930; Miles, 1950; Watson, 1942, 1953; Thayer, 1966). Bilgrami and Howie (1960) suggested the following reaction for the breakdown of pyroxene (and the small amounts of calcic plagioclase sometimes present) releasing calcium :



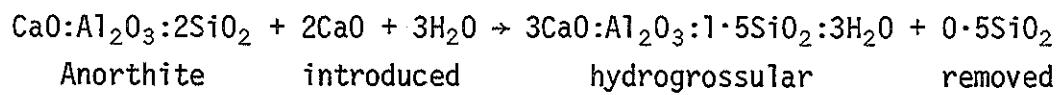
Bloxam (1954) also considered this hypothesis for the Ayrshire rodingites but maintained that they could not have been derived from the serpentinization of the ultrabasics since the latter, in this region, are dominantly harzburgites (olivine-bronzites). Instead he suggested that lime-rich hydrothermal solutions and CO_2 , which immediately post-dated the serpentinization, were responsible for the alteration of the gabbro to rodingite, and also produced local carbonatization of the serpentinite.

Studies of serpentinized ultramafic rocks (Bilgrami and Howie, 1960; Hess, 1964; Hess and Otalora, 1964; Page, 1967) showed that CaO , as well as Al_2O_3 , is lost during serpentinization. However, it is evident that the original composition of the ultramafic rock is important as Condie and Madison (1969) failed to note any systematic variations in CaO , Al_2O_3 , or Ni , with the degree of serpentinization, in dunites from North Carolina. By contrast Hess and Otalora (1964), who studied Mayaguez serpentinized peridotites, found that the maximum CaO content occurred in lherzolite (2.38%), whereas harzburgite contained 1.65 per cent and dunite 0.67 per cent. With increasing serpentinization the Al_2O_3 and CaO showed a tendency to decrease and it was suggested that these constituents were probably deposited in fractures in the rock to form hydrogrossularite.

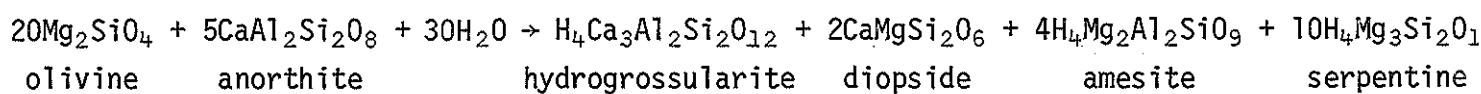
The source of the abundance of lime found in most rodingites has provided the main problem in the understanding of the origin of these rocks. Rodingites, as pointed out earlier, are found almost without exception associated with serpentinized ultramafic rocks - many of which contain too little original CaO to be always convincing as host rock contributors. For this reason the theories on origin proliferated and lime-bearing solutions had to be drawn upon from various sources, some of which remained obscure. It was even suggested that basic magma had been enriched in lime by the digestion and assimilation of limestone (Finlayson, 1909). Suzuki (1953) also considered this possibility for the origin of the Hokkaido rodingites but concluded that they were more probably derived from leucocratic gabbroic or dioritic rocks by lime-metasomatic processes.

De (1972), in reviewing the origin of calcium-rich assemblages, pointed out that although granitic rocks are normally poor in lime there are several examples known where they have formed lime-rich minerals in the late stages of crystallization. Calcium occurs more commonly in the anorthite molecule of plagioclase in granitic and dioritic rocks and is also a prominent constituent of hornblende present in the dioritic rocks. As pointed out by De (1972), available experimental data indicate that anorthite is unstable under a wide range of hydrothermal conditions. Attention was drawn to Ringwood's (1959) experimentation where he examined the role of high water concentration, and particularly the behaviour of OH^{-1} in silicate melts, and its effects upon crystal fractionation. It was established that the inhibition of anorthite crystallization causes Ca^{+2} and Si^{+4} to crystallize in the pyroxene or amphibole series which has the net effect of extending the field over which pyroxene or amphibole crystallize and restricts the plagioclase field. At the same time, the plagioclase which finally crystallizes is soda rich. Thus, anorthite crystallization may be inhibited under certain hydrothermal conditions leading to an enrichment of CaO and Al_2O_3 in the late-stage hydrous melt.

Coleman (1966) suggested an equation to explain the breakdown of plagioclase to hydrogrossular which is based on the assumption that ferromagnesians alter to chlorite (and tremolite-actinolite) :



O'Brien and Rodgers (1973), although providing petrographic evidence that ferromagnesians are indeed chloritized, doubted that all the chlorite they found adjacent to their Wairere serpentinites could have been derived from the breakdown of ferromagnesian minerals in the gabbros. De Waal (1969) also found that calcic plagioclase was partly transformed to hydrogrossular in the Tugela Randt Complex in South Africa, but, in addition, he noted that diopside was formed by the interaction of Mg in the olivine with the Ca in the feldspar. Superfluous Al went into the serpentine structure to form Al-rich colourless serpentine that has partially replaced the feldspar. He summarized the reaction by means of the formula :



When the amesite (which is an aluminous septachlorite) is combined with the serpentine it is found that Al constitutes approximately 6 per cent by weight of the mineral.

De Waal (1969) was of the opinion that the inability of serpentine to accommodate any Ca atoms in its structure, together with the fact that an increase in Si is required during serpentinitization, forms the basis for the formation of rodingite in ultramafic rocks. His studies led him to the conclusion that "when the fluids responsible for serpentinitization in the ultramafic host-rock attack the calcium-rich inclusions in the relevant host-rock, the plagioclase will first be broken down to calcium silicates, or calcium aluminates. Small amounts of sodium may be taken up in chlorite, or even in albite, when in greater abundance. The excess of calcium, owing to the inability of serpentine to accommodate this element, will remain a part of the advancing serpentinitization fluids - a phenomenon somewhat similar to the 'basic front' of Reynolds (1947). Superfluous aluminium presents no problem because this element can easily replace silicon in the serpentine lattice, which will then approach the aluminous septachlorite, amesite, in composition. At a late stage even the pyribolites may be destroyed - mainly because of the silicon deficiency during the serpentinitization process".

De Wall (1969) further maintained that very little calcium need be added from an external source. He argued that the high calcium content of rodingite is the direct result of the retention of this element in what he termed the mother-rock (usually cafemic in composition). The entire process is accompanied by a considerable volume decrease in the mother-rock - the extra space created being taken up by serpentine which in his example showed an increase in aluminium content (see also O'Brien and Rodgers, 1973).

De (1972), in describing the petrology of dykes of varying compositions (diorite, quartz monzonites, pegmatite, and albitite) intruded into serpentinitized harzburgite and dunite in the Appalachian region of the Eastern Townships of Quebec, concluded that the water-rich and silica-deficient environment of the serpentinitized ultramafic rock was responsible for affecting the normal sequence of crystallization of the dykes. He argued that the presence of a water-rich environment, provided by serpentinite, and containing upwards of 12 per cent water by weight, would effectively control the nature of the phases crystallizing from the dyke magma. Employing the experimental results of Ringwood (1959), De (1972) maintained that early formed pyroxene was converted to hornblende and finally chlorite and (or) biotite; while at the same time the crystallizing plagioclase becomes albitic. The lime and alumina that would normally form clinopyroxene or hornblende and plagioclase remain in the residual hydrous melt to form abundant lime-rich hydrothermal minerals. The lime in the rodingites is, according to this reasoning, therefore not derived by serpentinitization of the ultramafic wall rocks but is mainly available in the dyke magma, supporting, in this case, de Waal's (1969) contention that little calcium need be added from an external source.

Alberti et al (1976) described rodingites from North-eastern Iran that show an absolute prevalence of garnet (ranging from almost pure grossularite to an intermediate member of the grossularite-andradite series) and an almost total lack of hydrogarnet, the latter virtually having reached the point of characterizing a whole group of rodingites. Whilst conceding that rodingitization appears to be a process dependent upon a large supply of Ca, the availability of which must be genetically linked with serpentinitization, they pose that a matter of controversy might lie, not only with the timing of metasomatism, but also with the attribution of rodingites to processes of either local or regional extent. They find support for the suggestion that rodingites occur on reaction zones at the margin of, and sometimes within, diapiric ultramafic bodies emplaced at low temperature along major fracture zones in serpentinite terrane (Coleman, 1967; Vuagnat, 1967; Dal Piaz, 1969). This process, referred to as the "cold intrusion" hypothesis, is supported by Alberti et al (1976) although they point out that their North-eastern Iran rodingites display a conspicuous lack of low-temperature minerals. It is argued further that the geotectonic setting of the rodingite occurrences may represent an ancient suture between an oceanic and a continental plate, lending support to the suggestion, put forward by Honnorez and Kirst (1975), that serpentinitization and rodingitization pre-date the uplifting of the ultramafic bodies, and that they take place in the deeper oceanic crust.

Some support for the above contention may be forthcoming from stable isotope studies (hydrogen and oxygen) undertaken by Wenner (1975) on minerals that occur in rodingites found largely in association with lizardite-chrysotile-type serpentinites from North America and New Zealand. The data suggests that all the calc-silicate components present in these rocks (except for xonotlite and possibly pectolite, which appear to have formed from isotopically depleted meteoric waters) infer formation from non meteoric type waters. As extensive stable isotope evidence from previous studies indicate that lizardite-chrysotile-type serpentinites probably form from waters of meteoric hydrothermal origin, the isotopic evidence presented by Wenner (1975) suggests, therefore, that much of the metasomatism associated with the formation of rodingites appears not to have occurred in association with serpentinites of the type commonly observed with these rocks. Instead it is suggested that the main metasomatic alteration probably occurred earlier at depth during regional metamorphism, in association with antigorite-type serpentinitization.

VI. THE ORIGIN OF THE STOLZBURG RODINGITES -
DISCUSSION AND CONCLUSIONS

The previous section outlined the many options available when attempting to establish the petrogenesis of rodingites. As has been pointed out by numerous investigators two facts are pre-eminent. The first is the occurrence of these rocks as typically dyke-like bodies, or irregular-shaped pods or lenses, of original gabbroic or diabasic composition and, secondly, the association of serpentinized ultramafic rocks either, in contact with the rodingites or, within a short distance of their contacts.

Of the various origins that have been suggested for rodingitic rocks there emerge several broad categories which are summarized below :

1. the release of Ca mainly from pyroxenes (diopside-diallage) and Ca and Al from feldspar (anorthite molecule of plagioclases) both elements being released to form hydrogarnet during late magmatic or post-magmatic hydrothermal alteration of gabbroic rocks (Grange, 1927; Arshinov and Merenkov, 1930; Miles, 1950; Bilgrami and Howie, 1960).

2. magmatic (Cady et al., 1963) or contact-metamorphic processes (Turner and Verhoogen, 1960).

3. metamorphic-metasomatic processes, the latter resulting in a more or less complete replacement of former gabbroic rocks (Turner, 1933; Miles, 1950; Suzuki, 1953; Bilgrami and Howie, 1960; Coleman, 1967; O'Brien and Rodgers, 1973).

4. processes that allow for the retention and residual enhancement of calcium in gabbroic dyke-like bodies and which require very little supplementary calcium to be added from external sources (de Waal, 1969; De, 1972).

In the Stolzburg area it appears that no unique mode of formation of the rodingites can be singled out, and the writer is of the opinion that the processes established elsewhere in the world are so interrelated that a combination of mechanisms of origin will probably provide a fairer reflection of the petrogenetic history of these rocks.

Ca-rich phases are abundantly available in the Stolzburg layered body, commencing with the presence, in the central portion of the region, of clinopyroxenites (websterites and diopsidites), and plagioclase-rich gabbroic units. Interlayered with these rocks are a variety of serpentinized ultramafic assemblages. From the preceding descriptions of the field occurrence and petrography it is evident that all the requisite ingredients are present in the area to allow for the development of rodingites. All the component parts display signs of having been either serpentinized, uralitized, or saussuritized, thereby providing the mechanisms for the release of lime and alumina from the pyroxenes and plagioclases in the area and the subsequent garnetization or metasomatic replacement of available gabbroic dykes and lenses.

Just when these processes occurred remains conjectural. It is probable that some of the hydrothermal solutions responsible for the serpentinization of the ultramafic rocks were residual fluids (autometasomatic) trapped in the originally crystallizing magma. However, it is equally probable that at a later stage, following the emplacement of the diapiric tonalite gneiss plutons (Figure 2), further and possibly more severe, alteration of the Stolzburg assemblages was accomplished.

Nowhere in the field was it possible to trace any of the rodingite dykes into the successions located stratigraphically above the Rodingite Zone shown in Figure 5. All the dykes encountered penetrate downwards into the serpentinized dunites, suggesting, as was considered to be the case in Western Australia (Miles, 1950), that early tension cracks may have formed in the cooling ultramafic masses undergoing volume changes resulting from serpentinization. These cracks may have been rapidly filled by injection of an intermediate differentiate of composition near gabbro. The dykes thus emplaced were promptly modified to rodingite by the addition of lime from still heated, calcium-silicate charged, hydrothermal solutions circulating under pressure away from the serpentinized masses, and squeezed along the fractures, fissures and channels into which the gabbro had just been injected.

The entire process of rodingite formation appears to have been completed during the Archaean. This can be stated because early Proterozoic diabase dykes crosscut the layered sequence where rodingitization has been most active (Figure 5), yet are unaffected and retain their original mineralogy.

Rodingites, despite the lack of unanimity concerning their origin, provide an interesting study, if only for the fascinating variety of calc-silicate mineral assemblages encountered in these rocks.

* * * * *

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KEY TO PLATE 1

- A. View of part of the Stolzburg Ultramafic Complex looking northeast from the Stolzburg chrysotile asbestos mine (foreground). In the middle distance can be seen the layering of the ultramafic succession (as depicted on the geological map, Figure 5). Dunites, occupy the river valley seen above the mine dump, whereas the bush-clad ridges to the right consist of orthopyroxenites (enstatite-bronzite cumulates), the latter separated by more dunites (smooth, grass covered, areas). The rodingitic rocks, described in this paper, occur mainly in the area to the right of the second prominent orthopyroxenite unit.

The Doyershoek asbestos mine, which is not visible in the photograph, occurs just over the second pyroxenite ridge in the middle of the picture.

- B. Winding rodingite dyke crosscutting serpentinized dunites in the area southeast of the Doyershoek asbestos mine.

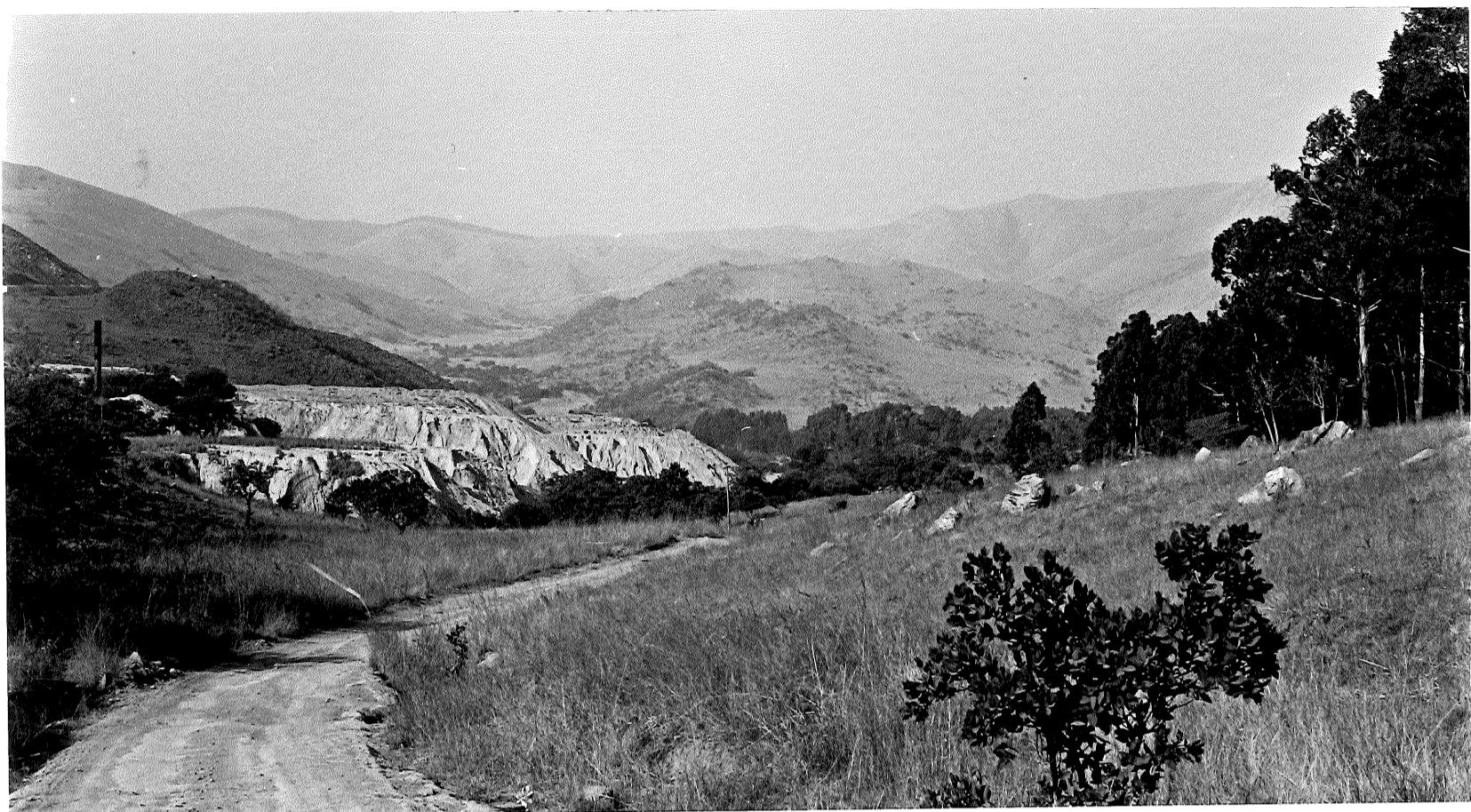
- C. View of one of the wide (up to 5 m in places) rodingite dykes intruded at right angles to the strike of the surrounding serpentinized dunites. The dykes usually have a positive expression being generally more resistant than the neighbouring serpentinites. In the background is a bush-clad orthopyroxenite layer. The rodingite dykes appear to be confined in their development to the dunite units alone.

- D. Narrow (10 cm wide) rodingite dykelet surrounded by serpentinized dunite in the area southeast of the Doyershoek mine. The dykelet has a narrow chill margin (up to 1 cm wide) on either side, in contact with the serpentinite. The central portion of the dyke has suffered differential weathering of the calc-silicate components.

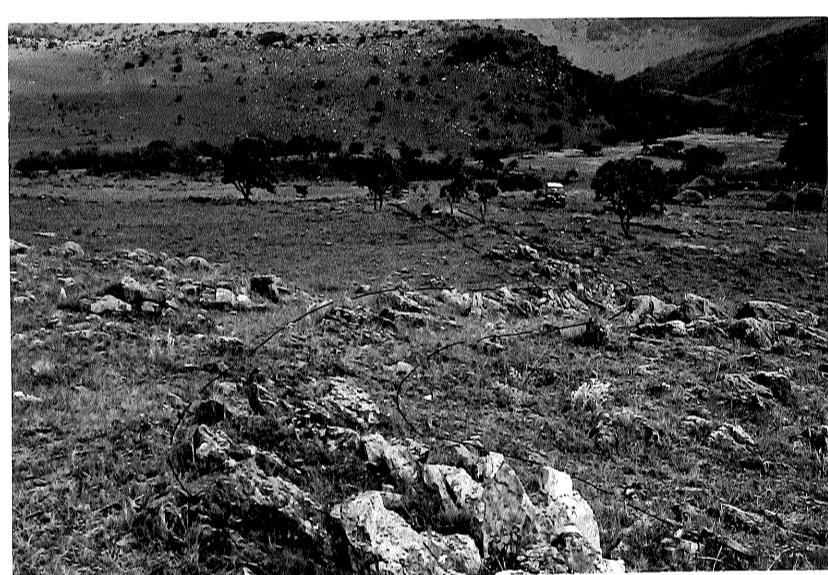
- E. Narrow "white dyke" of rodingite, again showing the typical positive field relationship with the surrounding serpentinized dunites. These calcium-rich rocks contain a wide variety of calc-silicate minerals including mainly hydrogrossular, hibschite, nephrite, vesuvianite, diopside, prehnite, and zoisite. Other components such as xonotlite, pectolite, and jurupaite may also be present but were not positively identified in this study.

PLATE 1

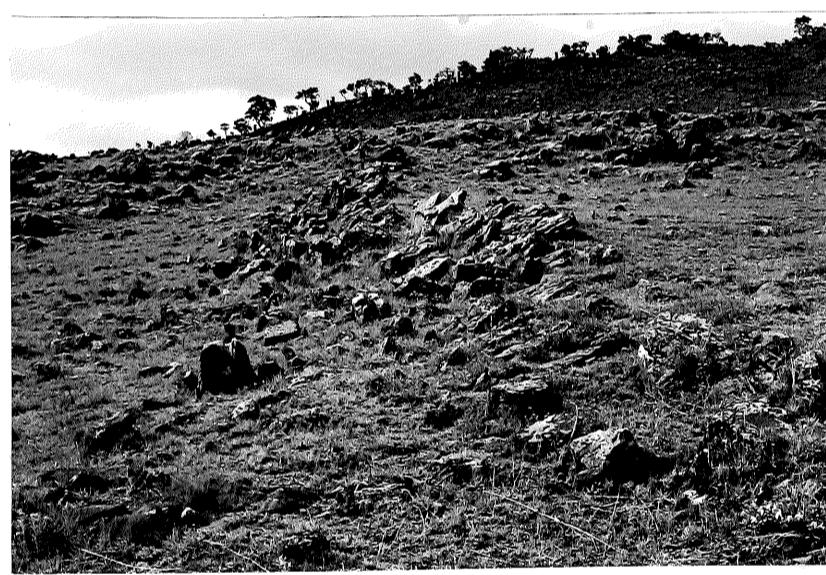
A



B



C



D



E



KEY TO PLATE 2

- A. Fine-grained chill contact of a rodingite dyke intrusive into serpentinitized dunite. The dyke is considered to have originally consisted of a mafic or intermediate gabbroic-type rock which was metasomatized by Ca-rich solutions, the latter derived from the expulsion of lime and alumina from calcic pyroxenes and plagioclases following serpentinitization, uralitization, and saussuritization of the country rock.
- B. Photograph showing fine banding at the contact of a rodingite dyke, the latter intrusive into serpentinitized dunites southeast of the Doyershoek mine. The light coloured bands consist almost exclusively of hydrogarnet (amorphous hydrogrossular and/or hibschite). The layers between the hydrogarnet contain some small round garnets (possibly grossularite or andradite), the latter mainly altered to chlorite. In addition, there is some nephrite, vesuvianite, diopside, and magnetite, as well as veinlets of prehnite. The matrix is, however, generally turbid and other phases that are present could not be identified.
- C. Photomicrograph showing weakly birefringent grossular (hydrogrossular) garnet, the latter displaying sector twins composed of pyramids with vertical axes meeting at the centre of the crystals. This twinning phenomenon, which is best seen under high magnification, has been described as being due probably to internal strain in the crystals (Deer et al., 1962).
- D. Banded pyroxene-plagioclase rock found in the Rodingite Zone near the Doyershoek mine. The pyroxene, which is diopside, shows partial alteration (uralitization) to secondary tremolite-actinolite. The white layers consist almost entirely of a fine mosaic of albitic plagioclase, the latter probably reconstituted from a more calcic plagioclase by the removal of lime (albitization). Also present in the rock is accessory zoisite, epidote, and sphene.
- E. Photomicrograph showing euhedral crystals of diopside (cumulate minerals) and secondary tremolite and Mg-rich chlorite (the latter occupying the spaces between the clinopyroxenes). Websterites like these (Table 1, column 5), on being altered, probably contributed considerable quantities of lime for use as Ca-metasomatizing fluids, the latter being responsible for the transformation of gabbroic dykes and lenses into rodingites.
- F. Photomicrograph showing plagioclase blades and laths being altered to zoisite and epidote (saussuritization). The breakdown of the anorthite molecule of plagioclase releases calcium making this element available as a contributor to the Ca-metasomatic fluids that altered the essentially gabbroic rocks present in the Rodingite Zone in the Stolzburg Ultramafic Complex.

PLATE 2

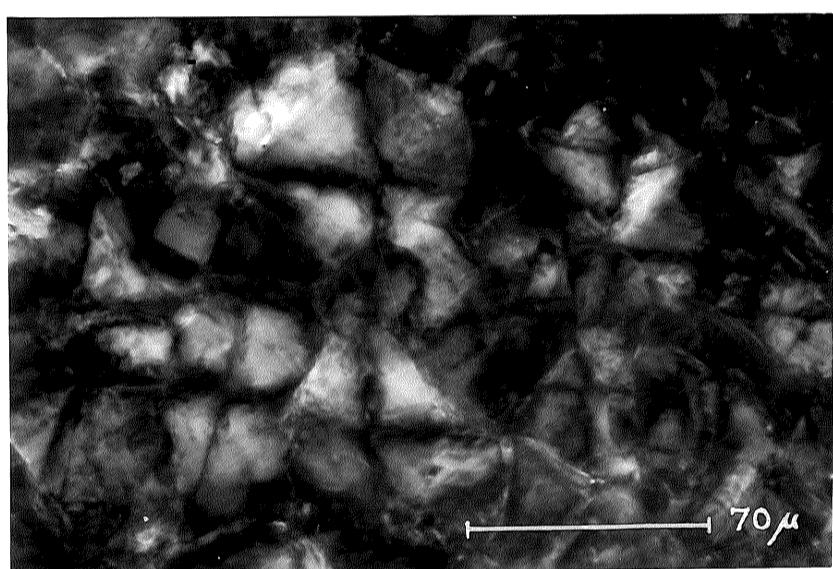
A



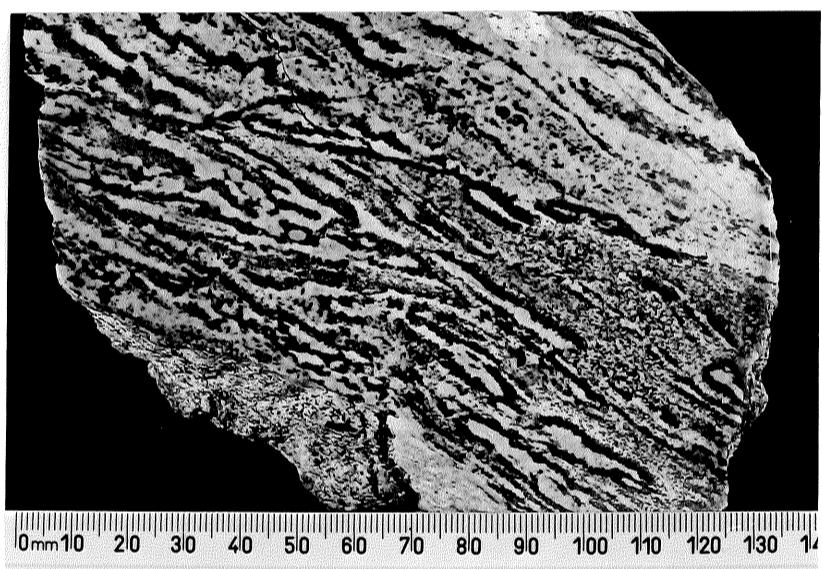
B



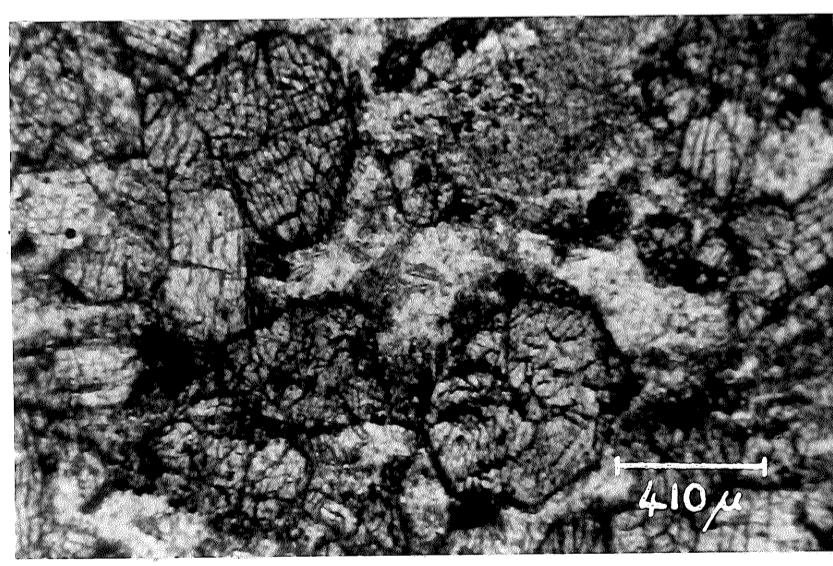
C



D



E



F

