production of mafic and ultramafic schists. Just why the verdite developed in some places and not in others could not be determined. The buddstone deposit north of the Worcester Gold Mine was formed in the limbs of the eastern half of the disharmonic fold and is located between the diabasic members of a small dyke-swarm.

In thin section the hard siliceous verdite consists of a microcrystalline quartz matrix that has partially or completely replaced the host-rock serpentinite. Scattered remnants or radiating blades of talc occur together with a fine, matted, greenish coloured phyllosilicate that resembles chlorite or sericite. Anhedral magnetite or nickeliferous magnetite grains occur scattered throughout this matted material and may be responsible for imparting to the rock the distinctive greenish colouration. The buddstone, in thin section, resembles in part the siliceous verdite, but the greenish coloured phyllosilicates occur as distinctive partings between a matrix of microcrystalline quartz and plagioclase (albite). The rocks show microscopic folds, a feature that is also prominent in hand specimens. Not much is known about the verdite and buddstone mineralogy. Clearly silica has played a major replacement role in the development of these rocks but there are possibly a number of silicate minerals too small to identify positively using standard petrological procedures.

* *

CHAPTER 4

THE HANDSUP - MUNDT'S CONCESSION ULTRAMAFIC IGNEOUS BODIES

A. INTRODUCTION

Numerous differentiated ultramafic bodies occur throughout the length and breadth of the Jamestown Schist Belt, but none are as well-developed as the Handsup and Mundt's Concession bodies west of Noordkaap. It has already been mentioned that the assemblages, comprising the ultramafic bodies and their associated rocks, have many similarities to the layered, essentially extrusive, successions of the Komati Formation, developed in the type-area on the southwestern side of the Barberton Mountain Land. Although the rocks from the two areas display entirely different modes of emplacement there are, nevertheless, certain criteria that suggest a common origin for the formations. The strongest arguments supporting their close relationship are found in the field associations and their relative position with respect to the stratigraphy of the Onverwacht Group as a whole. Due to the variation in modes of emplacement, petrological differences are considerable, yet, even here, there are grounds for mutual correlation between the two areas. Clearly, confirmatory evidence, possibly in the form of detailed major and trace element comparisons, is needed before the problems relating to their genesis can be satisfactorily answered.

It is the intention in this chapter to detail the field relations, petrography, and geochemistry of the Handsup-Mundt's Concession ultramafic bodies, and to discuss their petrogenesis.

B. GENERAL GEOLOGY

The regional distribution of the various differentiated ultramafic bodies in the eastern half of the Jamestown Schist Belt can be seen in Figure 5 (in pocket). However, for the purpose of this discussion, dealing more particularly with the Handsup-Mundt's Concession bodies, reference should be made to Figure 9, page 116.

The ultramafic bodies consist of a regular, alternating layered succession of rocks comprising a minimum of four differentiation cycles or pulses. Each of these cycles commences with a magnesium-rich ultramafic horizon which is generally completely serpentinized. The magnesium-rich layers in most cases consist of serpentinites derived originally from olivine peridotites. The basal, magnesium-rich zones are invariably followed by other serpentinite horizons containing slightly lower amounts of magnesium, but which are richer in calcium and ferrous iron. These rock-types were derived from original pyroxene peridotites. The serpentinized pyroxene peridotite layers may or may not give way to highly sheared zones comprising talc and tremolite schists or hard, brittle, slate-like serpentinized peridotites. The sheared or schistose rocks are always found in the contact zones between the softer, incompetent, serpentinized peridotites and the overlying, hard massive, more competent, altered pyroxenitic or gabbroic rocks.

Pyroxenitic rocks occur above the serpentinized pyroxene peridotites but generally these have been altered to amphibolites. The amphibolitized pyroxenite horizons are followed, in turn, by meta-gabbroic rocks. In the latter horizons, small patches of anorthositic gabbro were sometimes encountered. In some of the cycles the full range of differentiated products may be present, while in others, one or more of the units may be missing. The absence of a particular horizon may be due

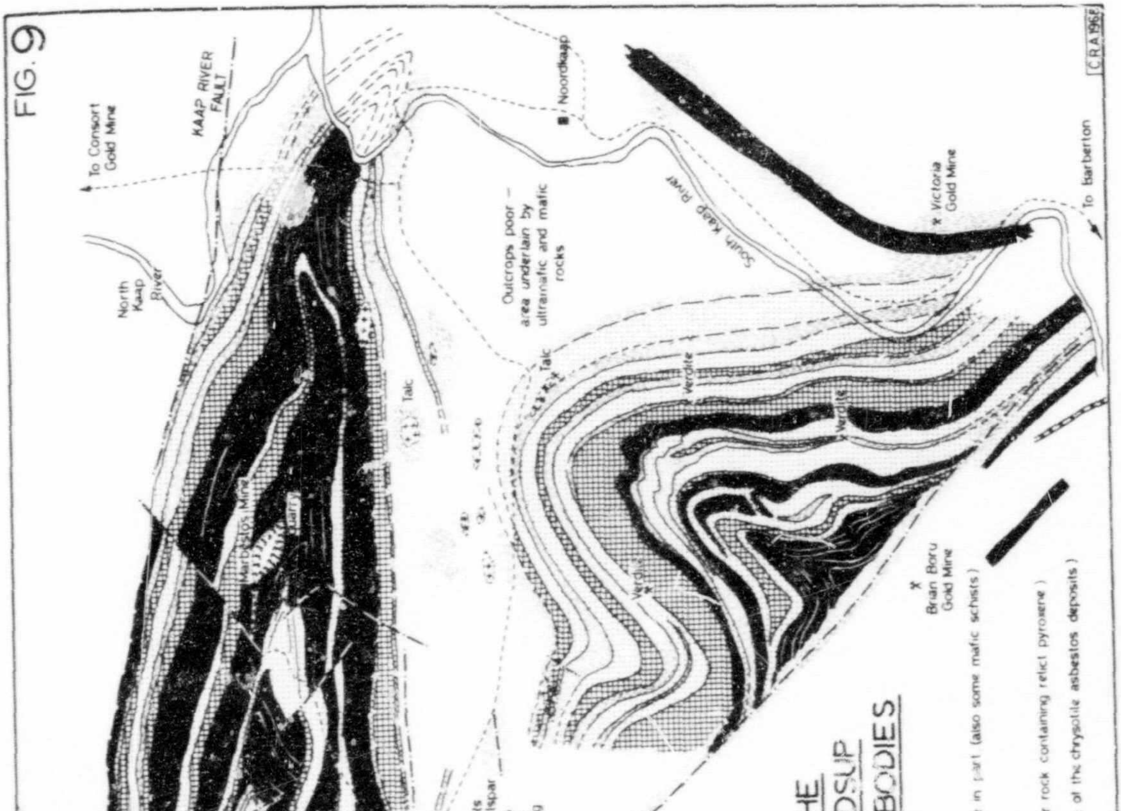


FIG. 9
GEOLOGICAL MAP OF THE
MUNDT'S CONCESSION-HANDSUP
DIFFERENTIATED ULTRAMAFIC BODIES
Quartz and felspar porphyries
Sheared and schistose ultramafic rocks - massive in part (also some mafic schists)
Pyroxenite, amphibolitized gabbroic rocks
Pyroxene peridotite - now serpentinized (nodular rock containing relict pyroxene)
Olivine peridotite - now serpentinized (host rock of the chrysotile asbestos deposits)
Scale
0
1/4
1/2
3/4
1 Mile
N
To Nelspruit
New Albion Talc & Gold Mine
Gold
Talc
Verdite Gold Mine
ALBION FAULT
Outcrops poor - mainly mafic and ultramafic schists and quartz-felspar porphyries Numerous talc workings along fault zone
Brian Boru Gold Mine
Verdite
Talc
Outcrops poor - area underlain by ultramafic and mafic rocks
North Kaap River
To Consort Gold Mine
KAAP RIVER FAULT
Noordkaap
South Kaap River
Victoria Gold Mine
To Barberton
C.R.A.1968

either, to incomplete differentiation within a cycle or, it may be due to structural disturbances having eliminated part of the succession.

A wide variety of mafic and ultramafic schists have resulted from the thermal and dynamic metamorphism of the area and these rock-types are particularly manifest in the synclinal area between the two major fold structures. Intrusive into the succession, in places, are the numerous porphyry bodies already mentioned, and which will be described in more detail later on.

The structure of the bodies has also been discussed but briefly, to recapitulate, the two major structures, viz. the Mundt's Concession fold and the Handsup fold, are anticlines, separated by a poorly exposed synclinal divide. The Handsup body is a disharmonic fold with a pronounced detachment along its southwestern base. The eastern and western extensions of the two bodies is obscured either, by poor exposure, a cover of younger rocks or, complex isoclinal folding.

C. PETROLOGY

(a) Mineralogical Notes

The rocks of the differentiated ultramafic bodies in the Jamestown Schist Belt represent the more highly metamorphosed equivalents of similar differentiated ultramafic bodies in the Kaapmuiden-Malelane area, in the northeastern part of the Barberton Mountain Land, and the Stolzburg body in the southwestern region. The mineralogy of the Jamestown Schist Belt ultramafic bodies seldom reflects their original composition. The rocks have, instead, almost invariably been altered by processes of serpentinization, steatization, sericitization, carbonation, silicification, chloritization, saussuritization and propylitization. Although only rarely could traces of the original mineralogy be seen it was, nevertheless, possible to accumulate sufficient evidence to enable direct comparison to be made with the less altered ultramafic bodies mentioned above. A comprehensive account of the petrography of the various members encountered in the Handsup-Mundt's Concession bodies is given in the following section.

(b) Petrography

(i) Serpentinized Olivine Peridotites

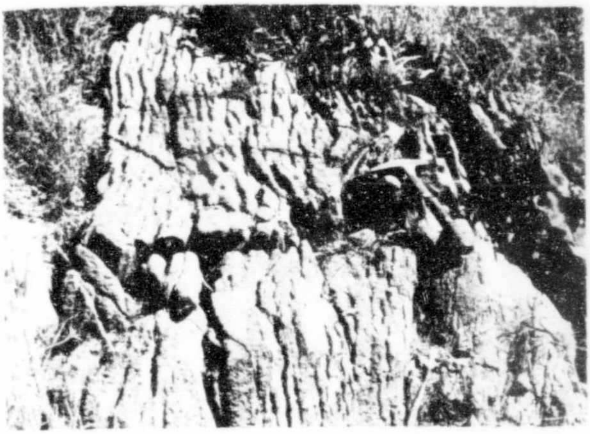
At the base of each cycle are found serpentinites, derived originally from rocks of olivine peridotite or even dunitic composition. In the field these rocks are distinctive and build massive ridges that stand out clearly on aerial photographs. The serpentinites are variously coloured, ranging from blue-black to blueish-green, grey, greyish-green, and yellowish-green. Outcrop patterns are extremely variable but generally a faint layering or pseudostratification can be determined where the successions have not suffered excessive structural disturbance (see Plate 7A, page 119). Frequently chrysotile asbestos cross-fibre is encountered in these rocks and appears to be closely associated with near vertical joints which are common throughout the area. The chrysotile fibre-seams or veinlets, which generally average between 1-5 mms in width, often develop in these joint planes, but except for a few places, the density and quality of fibre is poor. Many of the seams have been silicified, producing a hard, brittle-type of fibre. Narrow trains of magnetite are also closely associated with the chrysotile, frequently occurring as partings down the centres of fibre-seams. In a few localities where structural disturbance has been more intense than elsewhere, for example in the core of the Mundt's Concession fold and in the area just north of the detachment plane in the Handsup body, greater quantities of chrysotile fibre have been found.

Another typical outcrop style of some of the serpentinized olivine peridotites can be seen in Plate 7D, page 119. In this particular variety, the rock is strongly pitted, or pock-marked, but the reverse is sometimes the case with large nodules developed instead of pits. Magnetite is particularly abundant in some cases, forming positively weathering black specks scattered about the surface of the rock. In the Stolzburg ultramafic body, northeast of Badplaas, the writer has seen large fragments of magnetite derived from similar serpentinized ultramafic rocks, so that it would appear that the serpentinization process assisted in liberating and aggregating large quantities of iron, in the form of magnetite, when the olivine component was destroyed.

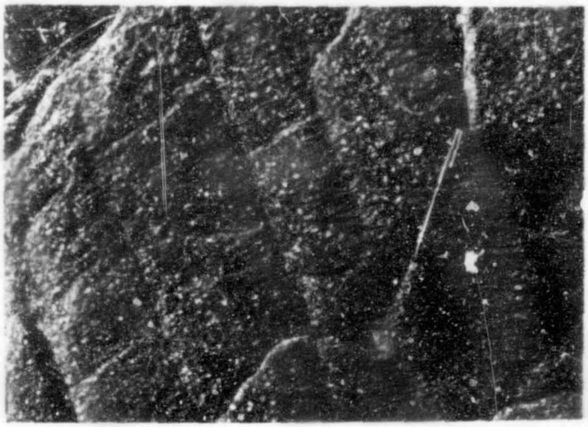
The serpentinites have, in some cases, been extensively altered to tremolite, talc, and carbonate. In places rocks altered in this way have subsequently been decarbonatized and converted back to serpentinite in a manner similar to that described by Naldrett (1966). Talc-carbonate alteration occurs frequently around the margins of serpentinized bodies, particularly the lensoid masses that have suffered shearing and attenuation. This form of alteration also takes place adjacent to fractures and joint planes in the serpentinites. In more altered rocks such as those shown in Plate 9B, page 125, the alteration has spread out from the cracks, and results ultimately, in the total replacement of the serpentinites by talc-carbonate rocks. The reverse of this process, namely decarbonation of the altered serpentinite, has also been observed in several parts of the area. Initially the carbonated rocks are altered

PLATE 7

A



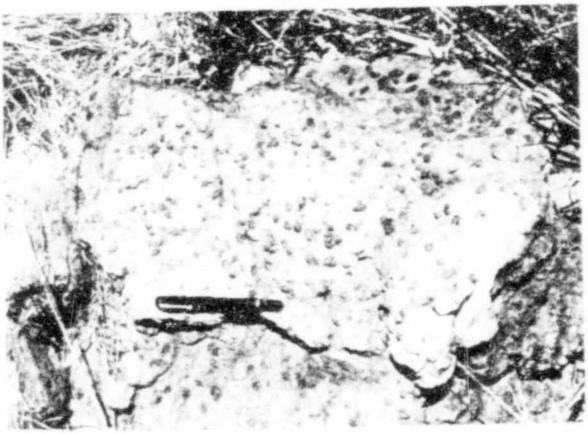
B



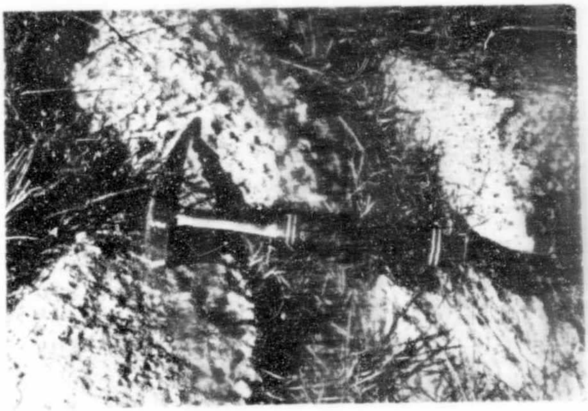
A. Pseudostratification or layering of a typical outcrop of serpentinized olivine peridotite from the Handsup - Mundt's Concession differentiated ultramafic bodies. Chrysotile fibre may be present in this rock-type.

B. Pyroxene phenocrysts on a weathered surface of a serpentinized pyroxene peridotite from the Handsup - Mundt's Concession bodies. Very often the pyroxene can only be detected as relict crystals under the microscope.

C



D



C. Positively weathering nodules of serpentinized pyroxene peridotite, typically found in the differentiated ultramafic rocks in the Jamestown Schist Belt. The pyroxenes are frequently partly, or wholly, converted to talc. The remainder of the rock consists of antigorite, serpophite, iddingsite and magnetite.

D. Outcrops of serpentinized olivine peridotite with a somewhat pitted or pock-marked surface weathering. The rock is apple-green or light grey-green in colour and has numerous aggregates of magnetite forming resistant, black specks on the surface. The rocks are highly magnetitic.

to serpentinite adjacent to the fractures or cracks. Often the rock is split up into a seri s of irregular, round, or oval, masses resembling "pebbles" or "boulders". Carbonated rims, having previously formed around these "boulders", are subsequently converted back to serpentinite by retrogressive alteration. An example of this phenomenon is shown in Plate 9A, page 125. The talc-carbonate alteration probably occurred at the same time as the widespread carbonatization which affected the rocks of the Jamestown Schist Belt. The possible source of the CO_2 may have been provided from the vast quantities of volcanic rocks existent in the area. These rocks may have liberated CO_2, either from the rocks themselves, from calcareous oozes associated with the pillow lavas, or from carbonate-filled amygdales. The intrusion of the granites may also have played a considerable role, both in supplying an additional source of CO_2 as well as assisting in the driving of the carbonates out of the rocks, down a temperature-pressure gradient. The contrasting decarbonatization, which appears to be confined to zones where jointing, fracturing, and faulting have occurred, suggests that the reversal in the alteration was somehow connected to a form of leaching of the carbonates by solutions that could move freely about the rocks.

The serpentinized olivine peridotites, in thin section, are comprised essentially of antigorite, tremolite, and secondary magnetite. In most cases the original olivine crystals have been completely altered and antigorite pseudomorphs after olivine are commonly encountered (see Plate 8A, page 122). Only in a few instances were small, high birefringent olivine kernels or cores seen in these rocks. Secondary magnetite, derived from the breakdown of the olivine, often occurs as a fine opaque dust throughout the thin sections, or may concentrate in clusters or aggregates. Frequently magnetite can be observed forming a black opaque rim around the antigorite pseudomorphs after olivine. Deuteric alteration of the original olivine also frequently results in the development of iddingsite, a reddish-brown mineral, which forms either a rim or a core to the altered grains. Another mineral often encountered is serpophite, a pale yellowish-green mineral associated with antigorite and which also occurs as vague patches in the centres of olivine pseudomorphs. Chrysotile fibres and blades may also appear in the serpentinite, either as randomly orientated laths, or as cross-fibre micro-veinlets (Plate 8A, page 122). Other minerals encountered in the serpentinized olivine peridotites are fibres, or jagged blades, of tremolite, and anthophyllite, and clusters and radiating blades of talc. Carbonate is very common in small amounts as a secondary mineral and may completely replace the serpentinite (see earlier, also Plate 9B, page 125). Carbonate pseudomorphs after olivine were seen in serpentinized peridotites in the Handsup body. In one instance on Lot 70, magnesite was found to occur with relict olivine cores, talc, antigorite, and some magnetite. In the Marbestos Mine quarry white veinlets and patches of opaline material occur in the serpentinized olivine peridotites and is probably the result of desilicification following the breakdown of the olivine to antigorite and chrysotile asbestos. This white opal accumulates, at times, in veins several inches wide in the chrysotile asbestos ore-body.

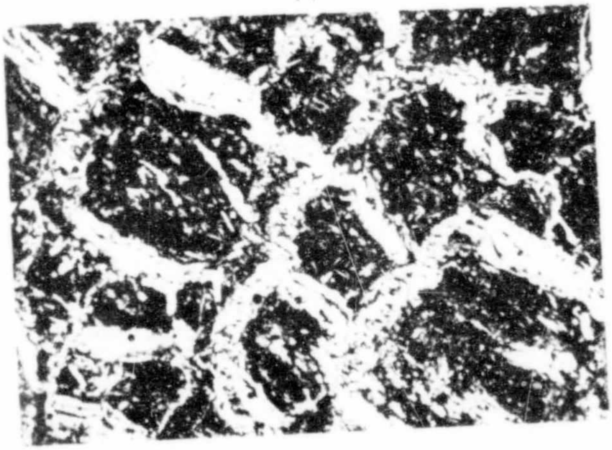
Three complete chemical analyses and one analysis lacking the FeO percentage are presented in Table 8, page 129. The chemistry of these serpentinized olivine peridotites can be compared with an average ultramafic rock which is listed in Table 8a, page 130. It can be seen that the magnesium values of the serpentinized olivine peridotites are very high, while at the same time, elements such as alumina, iron, calcium, titanium, and the alkalis are much reduced. The serpentinized olivine peridotites also have higher magnesium and lower alumina, iron, and calcium values than the overlying serpentinites derived from pyroxene bearing peridotites.

(ii) Serpentinized Pyroxene Peridotites

Immediately overlying the serpentinized olivine peridotites are serpentinites derived from original pyroxene bearing peridotites. The contact between the two rock-types is seldom clearly exposed but generally appears to be fairly sharp or weakly gradational, the transition taking place over a short distance of only a few feet. These serpentinites, which vary in thickness from a few feet to just under 1,000 feet in places, are distinctively different in the field to the serpentinites of the underlying succession. They once again build massive, resistant outcrops, the trends of which can be followed clearly both in the field and on aerial photographs. The rocks are generally darker in colour than the underlying serpentinites, being commonly dark blueish-black, blueish-green, greenish-black or dark grey in colour. On weathered surfaces they are very often reddish-brown or pale grey but this colouration seldom penetrates very deeply into the rocks. The outcrops are further typified by the occurrence of numerous, generally positively weathering, pyroxene phenocrysts, which stand out clearly on weathered surfaces (see Plate 7 B and C, page 119). On freshly broken surfaces, however, careful examination is necessary to observe the pyroxene blades which have suffered considerable alteration. Some of the pyroxene crystals measured between 5 and 10 mms in size and, as seen in thin section, are generally entirely surrounded by antigorite. The rock usually consists of a mass of fine antigorite, pseudomorphous after olivine, magnetite, tremolite, iddingsite, serpophite, and chrysotile, all products of the breakdown of the original olivine components of the rock. In addition, large euhedral grains of highly altered diopsidic augite or diallage occur scattered throughout the rock. Invariably the clinopyroxene has a well-developed

PLATE 8

A



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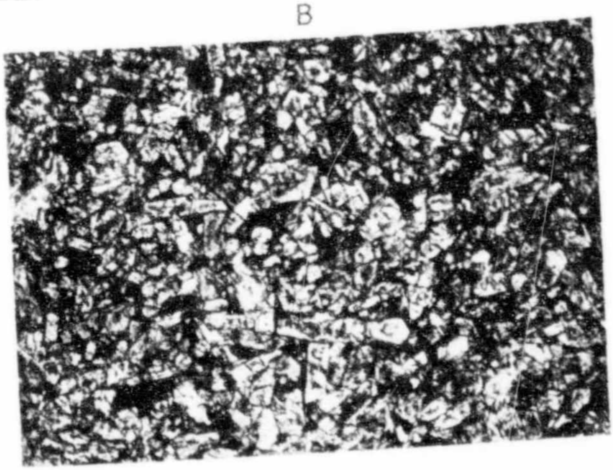
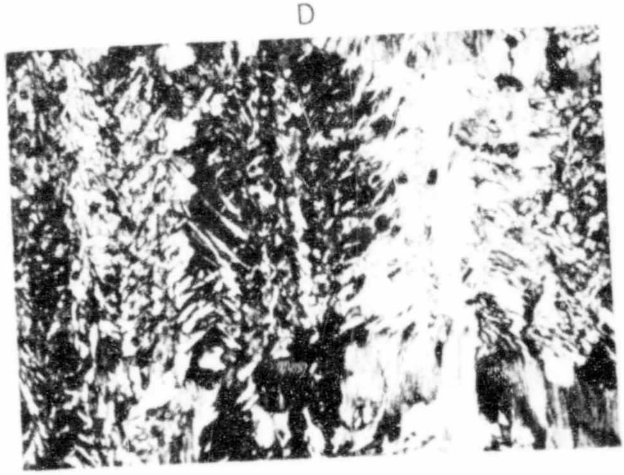


A. Photomicrograph (crossed nicols X75) of serpentinized olivine peridotite from the Marbestos Mine area on Mundt's Concession in the Jamestown Schist Belt. The photograph shows antigorite pseudomorphous after olivine, rimmed by chrysotile. Magnetite is also present.

B. Photomicrograph (uncrossed nicols X75) of a pyroxenite in the Mundt's Concession differentiated ultramafic and mafic body west of Noordkaap. The photograph shows a dense packing of euhedral clinopyroxene crystals. Invariably the pyroxenite has suffered transformation to amphibolite.

C

D



C. Photomicrograph (crossed nicols X75) of metagabbro from the Mundt's Concession body. Original calcic felspars have altered to albite, and pyroxene (crystal in centre of photograph) shows alteration to amphibole (dark rim around pyroxene core).

D. Photomicrograph (crossed nicols X75) of a band of asbestiform gedrite - cummingtonite and plagioclase, developed in altered pyroxenite of the Mundt's Concession differentiated body, west of the Marbestos Mine.

parting parallel to 100, and is mostly altered to talc. Fibrous, often light-coloured amphibole (uralite) often accompanies the talc. The uralitic amphibole is a deuteric or hydrothermal alteration product of the pyroxene. Very often the clinopyroxenes occur as large poikilitic plates enclosing antigorite. The antigorite, as mentioned previously, is clearly pseudomorphous after olivine.

Reconstructing the history of the rock, it would seem that the olivine settled out rapidly from a cumulate, trapping at the same time considerable amounts of intercumulus liquid. This intercumulus material crystallized as pyroxene on, and around, the existing cumulus olivines as soon as the temperature was lowered. The rocks thus appear to conform with the definition of an 'ortho-cumulate' proposed by Wager et al, (1960). These authors suggested that rocks of an accumulative origin (differentiated rocks) be termed "cumulates" and that this term be prefixed by ortho-, ad-, meso-, and hetero- to denote a particular course of crystallization of the intercumulus liquid (interprecipitate), after the initial accumulation of the crystals from a melt. The orthocumulates, being some of the commonest rock-types encountered in layered igneous complexes, thus consist of cumulus minerals surrounded by intercumulus material which has subsequently crystallized, completely enclosing earlier formed minerals.

Another mineral commonly encountered in the serpentinized pyroxene peridotites is chlorite, which is usually greenish in colour and which forms scattered aggregates or isolated patches throughout the rocks. Most of the chlorite seen, exhibits anomalous interference colours, ranging from intense blue, through mauves, and greenish browns, to dark brown. The mineral has probably formed at the expense of some pyroxene. Carbonates are also frequently encountered and are of secondary origin.

Another feature of the serpentinized pyroxene peridotites is the fact that they sometimes contain very poorly developed chrysotile fibre seams in places, but they never produce any chrysotile asbestos deposits. Generally their upper contacts with the overlying meta-gabbros and pyroxenites are strongly sheared and the serpentinites become hard and brittle, resembling black slate at times. The rocks appear to have suffered this alteration due to intraformational slip movements along the zone separating the more competent meta-gabbros from the softer, incompetent serpentinites. This zone of shearing, as has been explained elsewhere, is also thought to have been responsible for the production of the verdite deposits.

Chemically the serpentinized pyroxene peridotites reflect a slightly lower concentration of magnesium than the underlying serpentinites of the basal zones of individual cycles. There is also a marked increase in the amount of calcium and ferrous iron. The major element chemistry of a serpentinized pyroxene peridotite can be compared with other serpentinites and ultramafic rocks in Tables 8 and 8a, pages 129 and 130.

(iii) Pyroxenite and Amphibolitized Pyroxenite

Pyroxenites are rarely preserved in the Handsup-Mundt's Concession ultramafic bodies and are usually totally altered to amphibolite. A few isolated occurrences were found, however, where fresh pyroxenite could be examined. The freshest occurrence of a pure pyroxene bearing rock was located along the Marbestos Mine road, approximately half a mile from the turnoff on the Noordkaap-Nelspruit road. This area provides, in addition, an excellent section across the typical stratigraphy of one of the layered cycles. At the base the section commences with serpentinized olivine peridotite which is followed southwards by a zone of talc schist. The serpentinized pyroxene peridotite is unfortunately not evident in this area but the succession continues with a porphyritic, slightly amphibolitized pyroxenite, a fresh pyroxenite, and a typical outcrop of meta-gabbro, together with small anorthositic patches and veins (see Plate 9 C and D, page 125).

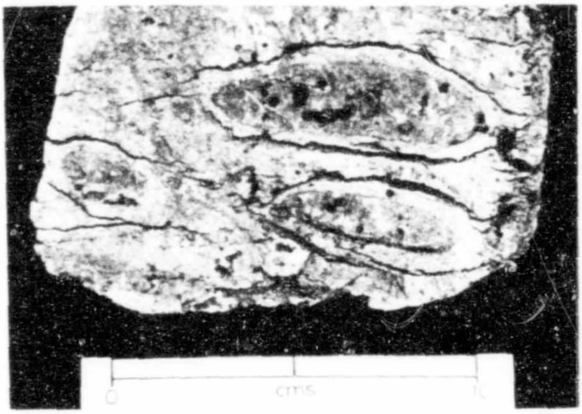
A further relatively fresh pyroxenite layer was found on the northern limb of the Mundt's Concession body about a quarter of a mile from the junction of two small creeks in the area of the Verdite Gold Mine (see Figure 9, page 116). Here too, a porphyritic variety of pyroxenite was found, the phenocrysts, however, having altered completely to green chlorite.

The pyroxenites, or their amphibolitized equivalents, produce massive, smooth weathering surfaces. Generally, the rocks do not form good outcrops and they, together with the meta-gabbros with which they frequently occur, form the narrow hollows or troughs between the massive serpentinite layers. The pyroxenites are exceptionally tough rocks, being extremely difficult to break with a small geological hammer. The outcrops, at times, consist of a pile of rounded boulders similar to the exfoliated boulders found so frequently along dolerite or diabase dykes.

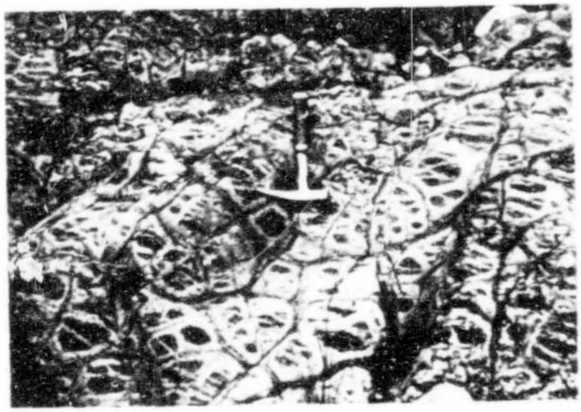
The fresh pyroxenite consists of a very fine-grained, pale green rock that weathers on surface to a reddish-brown colour. In thin section, the rock consists almost entirely of euhedral stubby prisms of clinopyroxene, the exact composition of which could not be determined. Most of the properties of the mineral shown in Plate 8B, page 122, however, suggested that the clinopyroxene is possibly diopsidic-augite. Apart from the clinopyroxene the mineral most frequently encountered in

PLATE 9

A



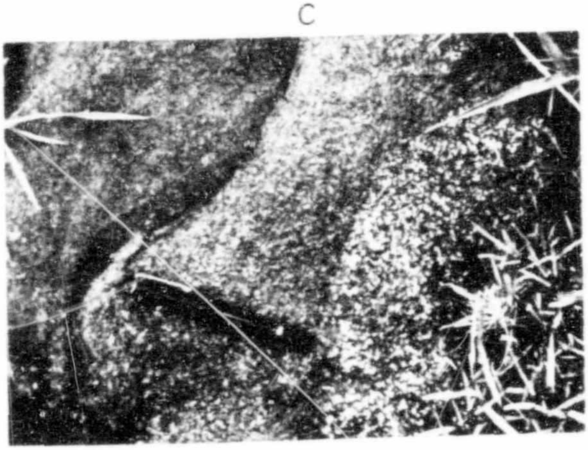
B



A. Specimen of serpentinized peridotite showing the development of small spheroidal "boulders" or "pebbles" which have a core of dark green serpentinite, surrounded by a rim of lighter green serpentinite. The outer rim appears to have altered initially to a talc-carbonate rock and has subsequently been converted back to serpentinite by retrogressive alteration in a manner similar to that described by Naldrett (1966). (Handsup body).

B. Weathered face of serpentinized peridotite, affected by talc-carbonate alteration. The talc-carbonate rock forms a thin sheath between the inner core of serpentinite (dark) and an outer envelope of steatite (grey). Locality - Noordkaap River east of the Kaffir Creek Talc Mines.

C



D

C. Outcrop showing various phases of meta-gabbro developed in the Mundt's Concession differentiated ultramafic body. The rock has generally been altered to amphibolite but some relict patches remain in which plagioclase is very abundant - the rock tending towards an anorthosite in places. Thin sections reveal albite and actinolite mainly, with relict pyroxenes and accessory sphene and quartz.

D. Typical outcrop style of the meta-gabbroic rocks found in the Handsup-Mundt's Concession differentiated bodies. The mottled surface is due to irregular patches of the rock containing greater amounts of plagioclase, or a coarse or fine texture. White veinlets of anorthosite (albite, An7) cut through the rock.

these rocks is actinolite. This metamorphosed product of the original clinopyroxene in the rocks, is strongly pleochroic in green, suggesting that the mineral has a high iron content. Accessory amounts of quartz, chlorite, felspar, magnetite, ilmenite, and leucoxene were also recorded.

Some outcrops of pyroxenite displayed narrow seams, measuring up to an inch in width, of a hard, siliceous asbestiform mineral. Optical examination as well as X-ray examination could not establish precisely what mineral was responsible for the pseudo-fibre. The fibrous, acicular, asbestiform laths are intricately intergrown with plagioclase felspar (see Plate 8D, page 122), producing a fine fishbone intergrowth pattern. The X-ray analysis suggested, however, that the mineral belonged to the amphibole clan and more specifically to the gedrite-cummingtonite members.

The least altered pyroxenite in the Mundt's Concession body was chemically analysed, the results of which are included in Table 8, page 129. Comparison of this rock can be made with an average pyroxenite (after Nockolds, 1954) in Table 8a, page 130. The values of silica, calcium, sodium, and potassium are higher, and alumina, iron, magnesium, and titanium are lower than the average chemistry of pyroxenites.

(iv) Meta-Gabbroic Rocks

Not infrequently, the pyroxenites, or amphibolitized pyroxenitic rocks just described, are either poorly developed or are not developed at all. In such cases the serpentinized pyroxene peridotites are immediately overlain by peculiar mottled- and gnarled-looking gabbroic rock-types, two examples of which can be seen in Plate 9, C and D, page 125. These rocks are developed in the low divides separating the serpentinite ridges, and, in many cases, fail to outcrop or else outcrop relatively poorly.

Sometimes so much scree and loose rubble has migrated down the slopes from the serpentinite ridges that they cover the outcrops completely. Perhaps the best exposures of the typical meta-gabbroic rocks and their variation products can be seen on the northwestern slopes of the Handsup fold. Here, well-defined layers of meta-gabbro resembling, in many instances, coarse-textured diabasic dykes, can be followed uninterruptedly around the fold structure before disappearing in an area of poor exposure (see Figure 9, page 116).

The outcrops of meta-gabbroic rock are distinctive, being much darker in colour than the average surrounding rocks. The texture is very variable ranging from a fine-grained variety to a coarse textured rock in which crystals, sometimes in excess of 5 mms, were seen. Particularly characteristic too, are the mottled surfaces mentioned previously. The rock is, like the pyroxenite described earlier, very tough and hard to break. In hand specimen, the most prominent minerals seen are amphiboles and felspar. In some rocks, amphibole makes up a large percentage of the composition, almost to the total exclusion of any other mineral. In others, felspar is very prolific, the rock approaching, at times, very nearly an anorthositic gabbro or even an anorthosite.

Thin section examination of the meta-gabbros revealed the presence of a wide variety of minerals and several interesting alteration phenomena are displayed. It is assumed that the plagioclase originally present in these rocks was of a calcic variety, presumably labradorite or bytownite. Evidence from identical rocks in the Kaapmuiden ultramafic bodies, where alteration has been negligible in places, shows that the gabbroic rocks all have a high anorthite content (R.P. Viljoen, verbal communication, 1968). In all the thin sections examined in the Jamestown Schist Belt the plagioclase was invariably found to be albite. This same relationship applied to the differentiated ultramafic bodies where the plagioclase was found to be albite (An7). In some instances the felspar is fresh-looking, but more commonly it has been saussuritized, the alteration products being clinozoisite and epidote. Sericitization of the felspars is also prevalent. The presence of the albite is not a result of albitization, but is due to the breakdown of the anorthite part of the plagioclase molecule. Epidote is formed during this process while albite remains in both twinned and untwinned form. A distinctive fibrous mineral is also commonly encountered in these rocks. It has low birefringence and parallel extinction and could represent one of the fibrous zeolites such as natrolite, mesolite, or thomsonite. Rocks containing this mineral are generally poor or lacking in plagioclase felspar and it is possible that the mineral is a propylitized product of the plagioclase.

Evidence was seen of original clinopyroxenes altering to amphibole. Relict grains and patches of pyroxene, showing good basal sections with right-angle cleavage, can be seen altering to green actinolite or uralitic hornblende, Plate 8C, page 122 shows a photomicrograph of a high birefringent prismatic core of clinopyroxene altering around the edges to actinolite. Chlorite, in some highly altered mafic rocks, is also associated with the uralitization process and may, at times, be the principal product of the breakdown of the ferromagnesians. The chlorite is usually pleochroic in green and has strong anomalous interference colours. More rarely, an occasional patch of talc or antigorite may be found.

Some of the amphiboles developed are in the form of long bladed crystals several mms wide and up to 20 mms in length. Outcrops of this metamorphosed, amphibolitic gabbro were found south of the Albion Fault in the area southeast of the Brian Boru Gold Mine. Ilmenite, either by itself, or intergrown with magnetite, is a common accesory mineral. In highly altered meta-gabbros the ilmenite has been altered to leucoxene, and sphene. At times small amounts of quartz were seen and carbonate occurs throughout as a secondary mineral.

A chemical analysis of a typical meta-gabbro from the Handsup ultramafic body is presented in Table 8, page 129 and, once again, its composition can be compared with an average gabbro determined by Nockolds (1954), and listed in Table 8a, page 130. Striking variations are evident in the alumina and magnesium contents of the rocks. The Handsup meta-gabbro has approximately half the alumina content and double the magnesium content of the average gabbro. The calcium, iron and sodium values coincide fairly well, while the silica, potassium, titanium, and phosphorus values show small variations.

(c) Chemical Data Relating to the Differentiated Ultramafic Bodies

A total of 7 chemical analyses covering all the various differentiation products typically associated with the ultramafic bodies in the Jamestown Schist Belt, and in particular, the Handsup and Mundt's Concession bodies, is presented in Table 8, page 129. Four analyses were carried out on serpentinized olivine peridotite, one sample each from the Handsup fold, and the differentiated body near the old site of Jamestown, and two samples from the Mundt's Concession body. The serpentinized pyroxene peridotite, and the meta-gabbro samples were obtained from the Handsup body while the pyroxenite was sampled in the Mundt's Concession body. The sample localities are plotted in Figure 5 (in pocket). As can be seen from the analyses the rocks are in a hydrous state, and contain high percentages of water. In order to obtain better, or more fully representative values for the various components the water (H_2O+ and H_2O-), and the carbon dioxide, was apportioned evenly among all the elements. The recalculated anhydrous values are listed in Table 8b, page 131.

The writer, requiring greater accuracy for the alkalis in the mafic and ultramafic rocks, carried out separate flame photometer analyses for the elements Na_2O and K_2O using a Zeiss PMQII spectrophotometer with flame attachment. These values were substituted for those listed in the tabulated chemical data supplied by the National Institute for Metallurgy.

The anhydrous values were used to calculate the cation percentages and Niggli molecular norms (Table 8c) and the Niggli values (Table 8d). The Niggli values are used to characterize the rock chemistry according to a scheme of 'magma-type' classification devised by Burri and Niggli (Burri, 1964). Modal analyses of six of the samples for which chemical analyses were obtained are listed in Table 8e.

TABLE 8

CHEMICAL ANALYSES : MAJOR ELEMENT CHEMISTRY (HYDROUS) OF SEVEN MAFIC AND ULTRAMAFIC ROCKS FROM DIFFERENTIATED ULTRAMAFIC BODIES IN THE EASTERN PART OF THE JAMESTOWN SCHIST BELT

	J3	CAN2	CAN30	CAJ18	CAN9	CAT40D	CAN10
SiO_2	44.79	40.23	40.06	40.30	42.44	54.97	54.30
Al_2O_3	0.86	1.53	2.20	1.54	2.34	3.65	7.14
Fe_2O_3	4.53	4.99	4.35	5.19	2.62	0.70	1.22
FeO	-	0.88	2.39	2.87	5.24	6.53	7.47
MgO	34.08	37.98	36.73	36.27	31.89	16.37	13.41
CaO	0.29	0.28	0.60	0.14	2.83	14.24	11.08
Na_2O	0.24	0.10	0.08	0.05	0.08	1.25	2.68
K_2O	0.03	0.01	0.02	0.01	0.02	0.03	0.10
H_2O+	10.26	12.07	11.58	12.16	10.28	1.48	2.10
H_2O-	1.01	0.42	0.34	0.07	0.20	0.15	0.02
CO_2	0.15	0.26	0.87	-	0.66	0.16	-
TiO_2	0.05	-	-	-	tr	0.24	0.40
P_2O_5	0.12	0.006	0.009	0.009	0.015	0.014	0.018
MnO	0.11	0.08	0.10	0.10	0.13	0.18	0.18
Totals	96.94	98.94	99.33	98.70	98.58	99.96	100.03

Descriptions and localities of samples listed in Table 8 :

J3 Serpentinized olivine peridotite - Mundt's Concession body, along Noordkaap-Consort Mine road. (Average of 3 comparative X-ray fluorescence and chemical analytical results. Analysts, National Institute for Metallurgy, and Corner House Laboratories)

CAN2 Serpentinized olivine peridotite - differentiated ultramafic body east of the old settlement of Jamestown.

CAN30 Serpentinized olivine peridotite - Mundt's Concession body, west of Marbestos Mine.

CAJ18 Serpentinized olivine peridotite - Mundt's Concession body, on road to Marbestos Mine, a quarter of a mile from the turnoff on the Noordkaap-Nelspruit road.

CAN9 Serpentinized pyroxene peridotite - northwest slopes of the Handsup ultramafic body.

CAT40D Pyroxenite - Mundt's Concession body, on road to Marbestos Mine, approximately a third of a mile from the Noordkaap-Nelspruit road turnoff.

CAN10 Meta-gabbro - northwest slopes of the Handsup ultramafic body.

All samples prefixed with 'CA' were analysed by the National Institute for Metallurgy, Johannesburg.

TABLE 8a

CHEMICAL ANALYSES : COMPARATIVE MAJOR ELEMENT ANALYSES OF MAFIC AND ULTRAMAFIC ROCKS

	1	2	3	4	5	6
SiO_2	40.16	43.54	43.07	40.50	48.36	40.03
Al_2O_3	0.84	3.99	4.20	4.10	16.84	1.91
Fe_2O_3	1.88	2.51	2.19	2.44	2.55	3.30
FeO	11.87	9.84	9.40	7.37	7.92	2.48
MgO	43.16	34.02	36.43	21.71	8.06	38.78
CaO	0.75	3.46	2.98	12.00	11.07	0.15
Na_2O	0.31	0.56	0.38	0.45	2.26	nil
K_2O	0.14	0.25	0.15	0.21	0.56	nil
H_2O+	0.44	0.76	0.64	0.47	0.64	11.82
H_2O-	-	-	-	-	-	0.70
CO_2	-	-	-	-	-	0.03
TiO_2	0.20	0.81	0.25	0.53	1.32	0.04
P_2O_5	0.04	0.05	0.05	0.09	0.24	0.01
MnO	0.21	0.21	0.26	0.13	0.18	0.08

Description of rock types listed in Table 8a :

1. Dunite, average of 9 samples (Nockolds, 1954).
2. Average peridotite, 23 samples (Nockolds, 1954).
3. Pyroxene peridotite, average of 11 samples (Nockolds, 1954).
4. Average pyroxenite, 46 samples (Nockolds, 1954).
5. Average gabbro, 160 samples (Nockolds, 1954).
6. Average of 9 samples of serpentinite calculated by the writer from analyses published by Maxwell et al, (1965).

TABLE 8b

CHEMICAL ANALYSES : ANHYDROUS VALUES OF 7 SAMPLES OF MAFIC AND ULTRAMAFIC ROCKS FROM JAMESTOWN SCHIST BELT DIFFERENTIATED BODIES

	J3	CAN2	CAN30	CAJ18	CAN9	CAT40D	CAN10
SiO_2	52.37	46.67	46.29	46.60	48.53	55.99	55.40
Al_2O_3	1.00	1.77	2.54	1.78	2.67	3.71	7.28
Fe_2O_3	5.29	5.78	5.02	6.00	2.99	0.71	1.24
FeO	-	1.02	2.76	3.31	5.99	6.65	7.62
MgO	39.80	44.06	42.44	41.94	36.47	16.67	13.68
CaO	0.33	0.32	0.69	0.16	3.23	14.50	11.30
Na_2O	0.28	0.11	0.09	0.05	0.09	1.27	2.73
K_2O	0.03	0.01	0.02	0.01	0.02	0.03	0.10
TiO_2	0.05	-	-	-	tr	0.24	0.40
P_2O_5	0.14	0.006	0.009	0.009	0.015	0.014	0.018
MnO	0.12	0.09	0.11	0.11	0.14	0.18	0.18
Totals	99.90	99.84	99.97	99.97	100.15	99.96	99.95

For description of samples and their localities see Table 8, page 129.

TABLE 8c

CATION PERCENTAGES AND NIGGLI NORMS :
MAFIC AND ULTRAMAFIC ROCKS

	CAN2	CAN30	CAJ18	CAN9	CAT40D	CAN10
Si	38.66	38.58	39.06	41.35	50.95	50.43
Al	1.73	2.49	1.75	2.65	3.96	7.81
Fe^{+++}	3.57	3.14	3.77	1.89	0.49	0.87
Fe^{++}	0.69	1.89	2.31	4.24	5.02	5.79
Mg	54.77	53.02	52.74	46.62	22.77	18.68
Ca	0.29	0.59	0.15	2.96	14.14	11.03
Na	0.19	0.14	0.10	0.15	2.23	4.80
K	-	-	-	-	0.05	0.10
Ti	-	-	-	-	0.16	0.27
P	-	-	-	-	-	-
Mn	0.04	0.09	0.10	0.10	0.16	0.16
Totals	99.94	99.94	99.98	99.96	99.95	99.94
Niggli Norms						
Ap	-	-	-	-	-	-
Il	-	-	-	-	0.32	0.54
Or	-	-	-	-	0.25	0.50
Ab	0.95	0.70	0.50	0.75	11.15	24.00
An	3.61	4.99	3.38	6.48	10.47	11.34
Mt	3.92	4.08	4.93	4.01	2.92	3.63
Wo	-	-	-	-	14.14	11.04
En	-	-	-	-	45.54	37.36
Fs	-	-	-	-	4.86	5.52
Q	-	-	-	-	10.14	5.86
Di	0.60	1.16	0.32	5.92	-	-
Hy	34.30	34.70	40.16	47.24	-	-
Ol	56.73	54.40	50.61	35.46	-	-

TABLE 8d

NIGGLI VALUES : MAFIC AND ULTRAMAFIC ROCKS

	CAN2	CAN30	CAJ18	CAN9	CAT40D	CAN10
si	64.5	64	66	73	112	118
al	1.5	2	1.5	2	4.3	9
fm	98	97	98	92	62	59
c	0.41	1	0.25	5	31	26
alk	0.16	0.08	0.08	0.1	3	6
k	-	-	-	-	-	0.02
mg	0.94	0.09	0.9	0.9	0.80	0.73

TABLE 8e

AVERAGE MODAL ANALYSES OF MAFIC AND ULTRAMAFIC ROCKS OF THE JAMESTOWN SCHIST BELT DIFFERENTIATED BODIES

Sample No.	Volume per cent	Weight per cent
CAN2		
Antigorite	61.97	56.20
Iddingsite	31.03	30.90
Magnetite	6.98	12.90
CAN30		
Antigorite	76.06	66.30
Iddingsite/serpophite	13.14	12.60
Magnetite	9.88	17.50
Chrysotile	0.89	3.60

TABLE 8e (Continued)

Sample No.	Volume per cent	Weight per cent
CAJ18		
Antigorite	64.94	58.00
Iddingsite/serpophite	25.66	25.20
Magnetite	9.23	16.70
Chrysotile	0.15	0.20
CAN9		
Antigorite	52.41	48.80
Tremolite	29.99	32.90
Magnetite	0.70	1.30
Chlorite	15.74	15.80
Carbonate	1.14	1.20
CAT40D		
Clinopyroxene	55.34	56.00
Amphibole	36.14	34.40
Quartz	0.36	0.30
Leucoxene	7.97	9.00
Magnetite	0.18	0.30
CAN10		
Actinolite	62.80	63.90
Anthophyllite	31.70	31.20
Carbonate	0.15	0.10
Plagioclase	3.50	2.90
Opaque Minerals	0.45	0.70
Chlorite	1.36	1.20

Niggli (1936) used the values si, al, fm, alk, k, and mg for the formulation of a system of magma-types in order to characterize the rocks' chemism. This refers exclusively to the chemical relations and therefore does not represent any form of rock classification. The "magma-type" is merely an abbreviated designation for the characterization of the chemistry, and the rocks actual mineral composition is not taken into consideration. A table of magma-types was devised by Burri and Niggli in 1945, and are again listed in a later publication (Burri, 1964). These authors devised a scheme whereby the chemistry of rocks could be referred to chosen standard magma-types having values of al~fm (approximately between 26 and 32), and which are generally termed isofalic.

Three magma series were formulated : the calc-alkali series, the sodic series, and the potassic series. This arrangement the authors justified by the fact that in nature a large number of igneous provinces are found, which are characterized by the common occurrence of magmas of one of these three series.

For the purpose of comparison and also to characterize the chemistry of the ultramafic and mafic differentiated assemblages of the Jamestown Schist Belt the Niggli values listed in Table 8d can be compared with some of the values and magma-types presented by Burri (1964). All the rocks comprising the ultramafic bodies in the Schist Belt fall into the calc-alkali series. The serpentinized olivine and pyroxene peridotites can further be grouped into the orthoaugitic-peridotitic class consisting of very strongly femic, basic and c-poor magmas. The two magma-types closely approximating the Niggli values listed in Table 8d are as follows :

	si	al	fm	c	alk	k	mg
(i) orthoaugitic	95	4	90	5	1	mostly	high
(ii) peridotitic	60	5	90	4	1	mostly	high

It can be readily seen that samples CAN2, CAN30 and CAJ18 can be classified as peridotitic, whereas sample CAN9 (the only serpentinized pyroxene peridotite), although also peridotitic, nevertheless tends towards the orthoaugitic type.

The amphibolitized pyroxenite and meta-gabbroic rocks of the differentiated ultramafic bodies cannot readily be matched by any of the magma-types listed by Burri (1964). The closest approximations, however, occur in the pyroxenitic magmas, which are femic to strongly femic, basic, alk-variable and c-rich. The two magma-types most closely approximating the Niggli values of samples CAT40D and CAN10, listed in Table 8d, are as follows :

	si	al	fm	c	alk	k	mg
(i) si-pyroxenitic	125	13	50	30	7	-	0.7
(ii) pyroxenitic	90	9	59	28	4	-	0.7

(d) Primary Magma Type

Two methods of determining or estimating the composition of the primary magma of the Handsup-Mundt's Concession differentiated ultramafic bodies have been tried : (a) summation of the compositions of the four principal rock-types comprising the differentiated layers of the intrusion, and (b) weighting the chemistry of the differentiated assemblages according to their relative abundance in the field. Although there are shortcomings in both methods, the two approaches, particularly the latter, permit some general conclusions, about the primary composition, to be made. In the first method (a), four analyses listed in Table 8, page 129 were used, viz. samples CAN2 (serpentinized olivine peridotite), CAN9 (serpentinized pyroxene peridotite), CAT40D (pyroxenite) and CAN10 (meta-gabbro), and an average value was determined. This value was recalculated anhydrous and is listed in Table 9 below, together with its hydrous equivalent. The bulk chemistry of these rocks indicates that the proposed composition for the intrusion is ultrabasic, carrying approximately 78.55 per cent normative femic minerals and 29.55 per cent normative olivine (see Table 9).

A possibly more realistic approach at attempting to get back to the composition of the primary magma is that outlined in the second method (b), mentioned above. A glance at the map of the Handsup-Mundt's Concession bodies (see Figure 9, page 116) shows immediately that the areal distribution of the rock-types of the layered intrusion suggests that the amount of ultramafic material in these bodies is greatly in excess of the amount of mafic material present. In order to obtain some idea of the relative abundance of the principal rock-types, a grid overlay, divided into tenths of an inch units, was superimposed over the geological map of the ultramafic bodies and a modal analysis was made. A series of east-west traverse lines across the map were selected using standard random number tables and samples or stations were plotted at one tenth of an inch intervals. Four rock-types were distinguished in the mode. These included the serpentinized olivine peridotites, the serpentinized pyroxene peridotites, the sheared or schistose interlayers between the mafic and ultramafic rocks and, lastly, the pyroxenite-meta-gabbro assemblage. The pyroxenites, due to their poor exposure and limited development, were grouped together with the more commonly encountered meta-gabbros. In all, a total of 833 counts were made, the

TABLE 9

AVERAGE ANALYSES OF SAMPLES RELATED TO THE FOUR PRINCIPAL DIFFERENTIATED PRODUCTS OF THE HANDSUP-MUNDT'S CONCESSION ULTRAMAFIC BODIES

	Average of 4 Samples, (N2,N9,N10,T40D)		Ultramafic Fraction (N2+N9)	Mafic Fraction (N10+T40D)	Average Weighted Composition	
	Hydrous	Anhydrous			Hydrous	Anhydrous
SiO_2	47.99	51.89	41.34	54.64	45.52	50.13
Al_2O_3	3.67	3.96	1.94	5.40	2.95	3.24
Fe_2O_3	2.38	2.57	3.81	0.96	3.02	3.32
FeO	5.03	5.43	3.06	7.00	4.22	4.64
MgO	24.89	26.91	34.94	14.89	29.45	32.43
CaO	7.11	7.68	1.56	12.66	4.77	5.25
Na_2O	1.03	1.11	0.06	1.97	0.61	0.67
K_2O	0.04	0.04	0.02	0.07	0.03	0.03
H_2O+	6.46	-	11.18	1.75	8.55	-
H_2O-	0.20	-	0.31	0.09	0.25	-
CO_2	0.27	-	0.46	0.08	0.35	-
TiO_2	0.16	0.17	tr	0.32	0.09	0.09
P_2O_5	0.013	0.013	0.01	0.016	0.01	0.01
MnO	0.14	0.15	0.11	0.18	0.13	0.14
Norms						
Or		.25			Or	.25
Ab		9.50			Ab	5.50
An		11.70			An	9.00
Σ salic		21.45			Σ salic	14.75
Mt		2.60			Mt	3.30
Il		0.20			Il	0.10
Di		14.40			Di	10.00
Ol		29.55			Ol	40.35
Hy		31.80			Hy	31.80
Σ femic		78.55			Σ femic	85.55

final mode being as follows :

serpentinized olivine peridotite	322
serpentinized pyroxene peridotite	214
sheared mafic and ultramafic schists	115
meta-gabbroic rocks and pyroxenites	182

The sheared schists were then apportioned equally to the adjacent serpentinized pyroxene peridotites and the meta-gabbroic rocks. The relative percentages of the three categories thus amounted to :

serpentinized olivine peridotite	38.6 per cent
serpentinized pyroxene peridotite	32.6 per cent
pyroxenite and meta-gabbro	28.7 per cent

The ratio of gabbro : pyroxene peridotite : olivine peridotite was found to be 1:1.14:1.35.

In order to simplify the calculations it was decided to group together the analysis of the serpentinized olivine peridotite (CAN2) with that of the serpentinized pyroxene peridotite (CAN9) and to call the combination the ultramafic fraction. Similarly the pyroxenite (CAT40D) was grouped together with the meta-gabbro (CAN10) and this combination is referred to as the mafic fraction. Average analyses for the two groups are listed in Table 9, page 137. The relative percentages of the two fractions are thus 71.3 per cent ultramafic and 28.7 per cent mafic. The ratio of mafic to ultramafic was calculated as being 1:2.5. In Table 9, is listed the possible average composition of the Handsup-Mundt's Concession magma weighted according to this ratio. The bulk chemistry once again indicates that the proposed composition of the magma is ultrabasic, carrying approximately 85.5 per cent normative femic minerals, of which normative olivine constitutes 40.35 per cent (see Table 9). The analysis is within the range of ultramafic rocks but is a little high in silica and calcium.

Most petrologists agree that layered ultramafic rocks form as a result of fractional crystallization of a parent gabbroic magma of tholeiitic type. This conclusion, however, is particularly applicable to gabbro-norite-peridotite intrusions such as those of Skaergaard, Stillwater, Muskox, the Great Dyke and the Bushveld. Although much has been written regarding ultramafic rocks, there appears to be a general paucity of information relating to very early Precambrian ultramafic layered intrusions. One of the few references to such an early differentiated ultramafic igneous body is that of Naldrett and Mason (1968). These writers described the geology of a differentiated sill and overlying lenses of ultramafic and gabbroic rocks in Dundonald and Clerque Townships, Ontario, Canada and concluded that the average composition of both the sill and the lenses appeared to be distinctly ultramafic. However, they were not at all certain about the composition of the liquid portion of the sill, stating that if all the olivine had been in suspension during intrusion, the liquid portion may have been gabbroic in composition rather than ultramafic. They considered, however, that the composition of the liquid portion of the lenses appears to have been ultramafic.

Theoretical and experimental petrology has for a long time precluded the possibility of ultramafic magmas or melts. Bowen and Andersen (1914) established the melting temperature of forsterite to be 1890°C and indicated that ultrabasic liquids rich in dissolved forsterite could only exist at very high temperatures. Bowen (1928) marshalled experimental and petrological arguments against the existence of liquid magmas more basic than basalt and advanced the crystal mush hypothesis for the intrusion of peridotites as an alternative to liquid ultrabasic magmas. One of Bowen's objections to ultrabasic magmas hinged around the fact that minor thermal effects were always found around peridotite masses. Vogt (1923) contended that dunites and peridotites were emplaced as liquid magmas with temperatures as high as 1500° to 1600°C. About Vogt's high temperature values for ultrabasic magmas Bowen (1928) wrote : "in view of the failure of inclusions of familiar rocks to show the remarkable effects they would undoubtedly experience upon immersion in such liquids, the temperatures mentioned can not be accepted". In addition Bowen (1928) argued that the high temperatures of the melting curves of ultramafic rocks, the large temperature interval between the geothermal gradients and these melting curves, as well as the discrepancy between observed magma temperatures and the minimum temperatures for the existence of true ultrabasic magmas, are important points against the existence of ultrabasic liquids in the earth's upper mantle and crust.

The numerous problems associated with the petrogenesis of ultramafic rocks led to what Hess (1955) termed a "magnificent argument" concerning the possible existence of liquid ultrabasic magmas. He pointed out that the field man invariably came to the conclusion that the ultramafic rocks appeared to have been very fluid at the time of injection, whereas repeated laboratory studies ruled out each new suggestion as to how such materials could be magmas at any reasonable temperature. Wyllie (1967), in his comprehensive review of the petrogenesis of ultramafic rocks, has shown that although there appears to be evidence to support the existence of low-temperature ultrabasic liquid magmas the two-sided argument still rages. It is, however, generally agreed that the source of the ultramafic material is in the upper mantle. After escaping from this initial source the ultramafic material could be in one of several physical states. The complete, or nearly complete fusion of this material would yield an ultrabasic liquid magma such as that postulated for the zoned ultramafic complexes of Alaska (Taylor, 1967). Partial fusion of upper mantle material could yield basaltic magma from which peridotites and pyroxenites may form by gravity settling. Examples of this type are the ultramafic cumulates in the Stillwater, Great Dyke and Bushveld Intrusions (Jackson, 1967) and the Muskox intrusion (Irvine and Smith, 1967). Partial fusion of the upper mantle could also yield a crystal mush composed of basaltic or picritic liquid and residual olivine crystals. High-temperature peridotites have this potential for partially melting to yield 10 to 20 per cent of basaltic magma (Green, 1967). Others, like those of the Lizard in Cornwall, may represent complete mobilization and intrusion to crustal levels of portions of mantle peridotite. This hypothesis, advocated by Green (1964), implies the existence of a high-temperature ultrabasic liquid, or liquid plus transported olivine crystals within the mantle.

From the literature it appears that support for the contention of a liquid ultrabasic magma is by no means firmly established. However, in the western half of the Jamestown Schist Belt, mapped recently by N.C. Harte, the writer has seen unequivocal evidence of intrusive magmatic ultrabasic material in the form of thin, dyke-like veins of serpentinized peridotite, cross-cutting other, more massive, layered serpentinized ultramafic horizons. The outcrops, exceptionally well-exposed in a gorge in the North Kaap River, leave no doubt in the writer's mind that, despite laboratory experimental evidence, liquid ultrabasic material can, and in fact, does exist. Furthermore, evidence of extrusive ultramafic lava flows, containing pillow structures, has been found in the Komati Formation in the southwestern part of the Barberton Mountain Land by Viljoen and Viljoen (1968; manuscript in preparation, 1969). These ultramafic lavas are of a type hitherto undescribed and have a distinctive chemistry, which can probably be ascribed to the fact that these rocks represent parts of the oldest ultramafic assemblage yet discovered on earth. As has been mentioned previously these rocks form an integral part of the Komati Formation and the writer has equated them with the essentially similar, yet intrusive assemblage of differentiated ultramafic rocks on the northern flank of the Mountain Land. Although a great deal of additional work is necessary on these ultramafic Archean assemblages in the Barberton greenstone belt the writer, nevertheless, firmly supports the contention that the differentiated ultramafic assemblages as typified by the Handsup-Mundt's Concession bodies, as well as others on the northwestern flank of the Barberton Mountain Land represent the products of a very primitive ultrabasic magma associated with the initial magmatic phase of the Barberton greenstone depository.

(e) Cyclic Units and their Origin

Due to the strongly folded nature of the Handsup-Mundt's Concession differentiated bodies, which probably resulted in thickening of the layered successions in the cores of the folds and thinning along the limbs of the structures, no accurate thickness of the full succession is available. Most of the layered horizons appear to be vertically dipping, allowing a rough estimate in thickness of between 4500-5500 feet to be made. Within the complete section of approximately 5000 feet at least four cycles of layer repetition occur, which are similar to the "cyclic units" recognized by Jackson (1961) in the Stillwater complex and Irvine and Smith (1967) in the Muskox intrusion.

The sequence olivine peridotite-pyroxene peridotite-pyroxenite or meta-gabbro is repeated regularly throughout the succession and the individual layers are visibly distinguishable in the field. All of the cycles commence with layers in which olivine is the principal cumulate mineral (i.e. the serpentinized dunite or olivine peridotite). Each cycle may thus reflect a major renewal of the composition of the magma by the introduction of fresh liquid of a similar composition to that of the earlier liquid, part of which has crystallized. Abbott and Ferguson (1965) have pointed out, however, that during fractional crystallization of magma the relative proportions of the different phases can frequently vary by a number of mechanisms, thereby producing rhythmic layering. These include crystal nucleation and accumulation in a manner resulting in alternating layers rich in one or more constituents. Differing rates of settling (Hess, 1938), convection currents (Wager and Deer, 1939), and undercooling and preferential nucleation (van Zyl, 1956, 1959, and Wager, 1959) are additional processes that have been postulated to explain layering in basic intrusions.

Just what mechanism, or mechanisms, may have been responsible for the production of the cyclic units in the Handsup-Mundt's Concession bodies are not known. Gravitational settling of mineral grains in practically any magma-type is almost inevitable. Periodic convection currents, although not entirely discounted, would seem to be more probable in very large bodies such as the Bushveld, Skaergaard and Still-water intrusions. If fresh magmatic liquid was repeatedly introduced into the system it would be required to circulate and replenish the entire body with magma similar in composition to that of the earlier liquid. The introduction of new magma into an intrusion would probably have entered in a manner similar to that described for the Muskox intrusion by Irvine and Smith (1967). The most probable access route would have been along the length of the intrusion in the space below the roof and above previously formed layers. This mechanism of internal flowage within the intrusion suggests to the writer, however, that some turbulence would be set up in the system which would possibly manifest itself in the local disruption of the regular layered successions. Fluctuating nucleation of the various minerals relative to each other, brought about by undercooling, seems to be a more likely explanation for the rhythmic layering.

(f) Fractionation

The chemical analyses listed earlier in Table 8, page 129 show the change in composition in the sequence comprising serpentinized olivine peridotite, serpentinized pyroxene peridotite, pyroxenite and meta-gabbro. The rocks originally rich in olivine are relatively low in SiO_2, Al_2O_3, total iron, CaO, the alkalis, TiO_2, and MnO, but are relatively high in MgO and total water. Reading from left to right across the analyses from CAN2 (serpentinized olivine peridotite) to CAN10 (meta-gabbro) there is clearly evident a progressive increase in the first group of oxides and a decrease in MgO and H_2O. Although the samples are not all from one differentiated cycle they are, nevertheless, representative of the typical rock-types belonging to each cycle. The variation in chemistry would thus reflect a variation in the composition, corresponding with height above the floor of each cycle. This, in turn, corresponds to successive stages of fractional crystallization of the magma.

The fractionation trend is, perhaps, more clearly demonstrated graphically (see Figure 10, A and B, page 143) where the analyses have been plotted on F.M.A. diagrams using, in the one instance, the molecular proportions of $Fe^{2+} + Mn^{2+}$, $Na^+ + K^+$, and Mg^{2+} (Figure 10A), and using in the other case (Figure 10B) the oxides $FeO + Fe_2O_3$, $Na_2O + K_2O$, and MgO. A smooth curve can be drawn through the points, most of which tend to concentrate along the iron and magnesium tie-line, particularly where these points are representative of the serpentinized olivine-rich cumulates. There is a weak to moderate tendency for enrichment of successive cumulates in iron, and, to a lesser extent, alkalis during the fractional crystallization of the Handsup-Mundt's Concession magma. For comparison the fractionation trends of the Losberg Intrusion (Abbott and Ferguson, 1965) the Bushveld Complex (Daly, 1928, and Hall, 1932) the Karroo dolerites (Walker and Poldervaart, 1949) as well as the Dundonald and Clerque differentiated bodies (Naldrett and Mason, 1968) have been plotted together with the Handsup-Mundt's Concession fractionation trend. It can be seen that these magmas are far more enriched in iron and alkalis. Both the Losberg and the Dundonald-Clerque bodies commence their fractionation with relatively high magnesium values, but both get progressively more enriched in alkalis and iron than do the Jamestown Schist Belt occurrences.

HANDSUP AND MUNDT'S CONCESSION DIFFERENTIATED ULTRAMAFIC BODIES

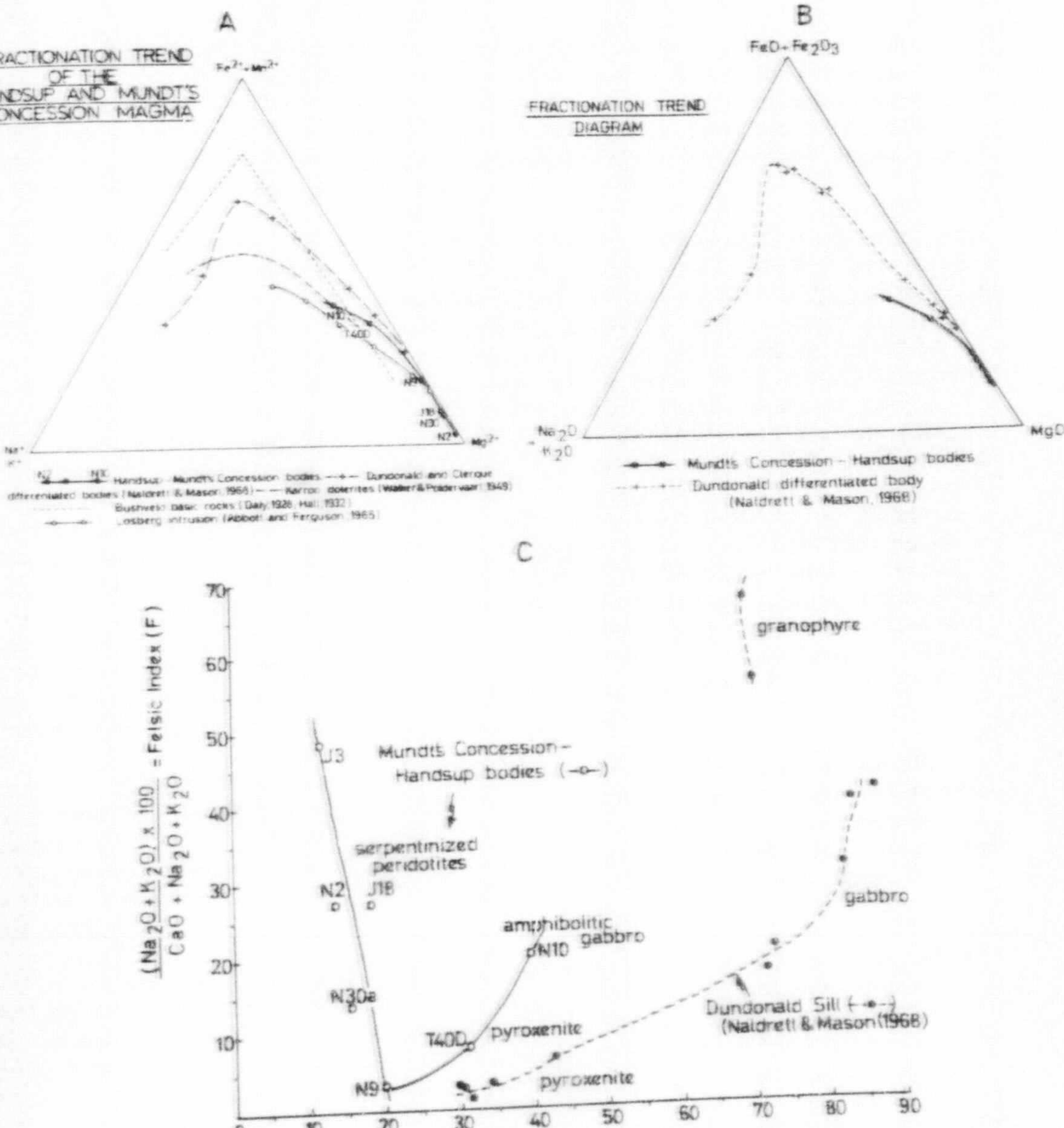


FIGURE 10 : A. Fractionation trend of the Handsup-Mundt's Concession magma plotted for comparison against various ultramafic and mafic differentiated bodies.

B. Similar fractionation trend plot using metal oxides.

C. Plot of the Mafic Index against the Felsic Index of rocks of the Handsup-Mundt's Concession bodies and the Dundonald differentiated body in Ontario, Canada.

All the examples superimposed on the Handsup-Mundt's Concession trend, except possibly the Dundonald-Clerque trend, are derived from magmas initially of gabbroic or basaltic composition. The lack of correspondence between the fractionation trends of the comparative examples is further support for the contention that the Handsup-Mundt's Concession **magma was** initially ultrabasic in composition.

Petrologists could argue that the late differentiation products (gabbro, norite, granophyre) of the Barberton ultramafic bodies have been removed by erosion, and that the full story is not portrayed in the various ultramafic occurrences in the area. This, however, can clearly be discounted because, in the Kaapmuiden area, the ultramafic bodies known as the Ship Hill body, the Budd body and the North Canal body are sandwiched between lava and chert horizons of the Onverwacht Group (Viljoen and Viljoen, verbal communication, 1968). These ultramafic bodies are thus unequivocally sills, their differentiation products being almost identical to those of the Handsup-Mundt's Concession ultramafic bodies. It can be confidently stated that no major late differentiated noritic or gabbroic fraction developed in these bodies or in any of the other differentiated bodies along the northwest flank of the Barberton Mountain Land. In the Jamestown Schist Belt the various ultramafic occurrences are so intimately associated with meta-volcanics, being always surrounded by them, that the writer unhesitantly regards them as also being sill-like in origin. The structural complexity of the area,however, does not permit a 'floor' or a 'roof' for these bodies to be defined accurately.

The smooth fractionation curves plotted in Figure 10A and B, using chemical data from the serpentinized olivine and pyroxene peridotites, the pyroxenite and the meta-gabbroic cumulates, indicates, furthermore, a strong genetic relationship between the various members of each cycle, and is added proof to support the contention that they all formed from the same magma.

The mafic and felsic indices of the Handsup-Mundt's Concession and the Dundonald Sill (Naldrett and Mason, 1968) were calculated and are compared in the variation diagram appearing in Figure 10C, page 143. The felsic index (F) provides a convenient index of the degree of fractionation of the felsic minerals (chiefly felspars) while the mafic index (M) is used as an index of mafic fractionation (olivine and pyroxene), Simpson (1954). The diagram enables the variation of each analysed rock to be traced out over the whole differentiation series. The plotted points can be joined by smooth curves representing the liquid line of descent. Like the triangular F.M.A. diagram (total iron-magnesia-alkalis) the M-F diagram is generally useful for demonstrating the variation trends associated with changes in the iron ratio which itself tends to vary depending on the alkali/lime ratio.

In both examples shown in Figure 10C the mafic and felsic fractionation have operated simultaneously to influence the trend of differentiation. The Handsup-Mundt's Concession rocks, however, only indicate the trend of differentiation in the pyroxene peridotite-pyroxenite-meta-gabbro assemblages, the serpentinized olivine peridotites plotting in an unsystematic manner due to the fact that the chemistry of the rocks has become variable owing to the influence of the processes of serpentinization. Comparison of the chemical analyses of serpentinite and unaltered dunite or peridotite (cf. Table 8, page 129 and Table 8a, page 130) shows that the most important changes that occur in the rocks, on serpentinization, are the lowering of most of the values of the oxides and the raising of the H_2O content. In particular, the more significant changes hinge around the oxides of CaO, Al_2O_3, the alkalis and TiO_2. The effect on the CaO and alkali values is extremely variable from one serpentinite to another, making it difficult to define the chemistry of an "average serpentinite". The felsic index of serpentinites is therefore an extremely variable, and hence unreliable, entity.

Another type of variation diagram, namely the Fe - Mg - Ca weight per cent diagram, is presented in Figure 11A, page 146. In this diagram the trend of the various rock-types reflects the variation in their mineralogy. The olivine peridotite rocks cluster about, or close to, the Fe - Mg join. With an increase in the pyroxene content of the rocks the points extend in towards the centre of the triangular diagram where, ultimately, are plotted the pyroxenites and meta-gabbroic rocks. Furthermore, it can be seen from the diagram that there is a dominant trend towards calcium enrichment and magnesium depletion. Iron shows only a slight enrichment throughout. Once again the rocks of the Dundonald and Clerque ultramafic bodies have been included in the daigram for comparative purposes.

Variation diagrams for two other components of the chemistry of the ultramafic rocks of the Handsup-Mundt's Concession bodies were plotted in Figure 11B. The first is the Al_2O_3 trend, the ordinate of which is on a linear scale while the second variation diagram, that of MnO, has a logarithmic ordinate scale. The differentiation index chosen for the abscissa in both cases is the FMC index of Naldrett and Mason (1968). The FMC values have no absolute meaning and are derived from the Fe - Mg - Ca diagram (Figure 11A). The position of a rock along the trend line is used as an index of its position in the differentiation sequence. The division boundaries have been extended perpendicular on each side of the trend line in the triangular diagram. These division boundaries are used as the unit along the abscissa. Rocks are plotted on the diagrams according to the division in which they fall on the Fe - Mg - Ca diagram.

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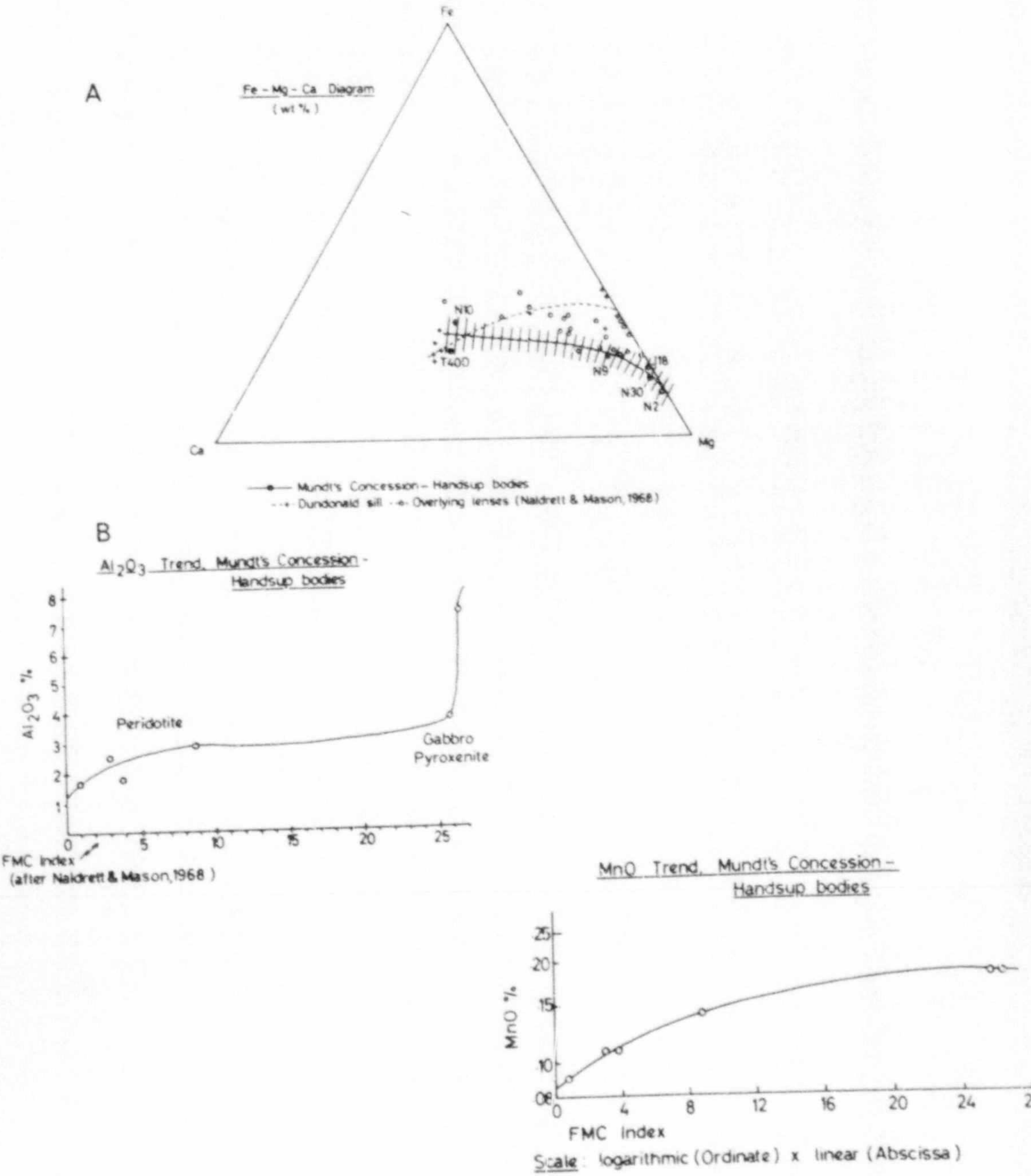

FIGURE **11** : A. Fe-Mg-Ca variation diagram (in wt %) comparing the Barberton example with the differentiated ultramafic Dundonald Sill in Ontario, Canada.

B. Al_2O_3 and MnO trends of the Handsup-Mundt's Concession bodies. The ultramafic rocks are plotted on the basis of the FMC index after Naldrett and Mason (1968).