

1986/28. Ultramafic-mafic complexes of western Tasmania and Platinum Group Element (PGE) minerals.

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Abstract

Platinum group element (PGE) minerals have been mined in the past from placer deposits associated with some of the ultramafic-mafic rocks of western Tasmania. Recent studies have shown that the ultramafic complexes can be divided into three groups on their mineralogy and chemistry. All past 'osmiridium' deposits are associated with one of these groups, the LDH succession. Another of the groups, the LPG succession, has recently been shown to have platinum-palladium sulphide and 'osmiridium' minerals associated with zones of chromite concentrations in one of the ultramafic units.

INTRODUCTION

Because of the recent interest by exploration companies in the possibility of PGE deposits in western Tasmania, and to requests for information 'in press', the following report has been compiled. The report consists of a brief literature summary of reports on PGE deposits in Tasmania; the abstract of the paper "Geology and platinum-group element (PGE) geochemistry of the Serpentine Hill Complex, Dundas Trough, Western Tasmania"; and, as Appendix 1, the section on the ultramafic-mafic complexes of western Tasmania which will be included in Geological Survey Bulletin 62, due to be published in the near future.

BACKGROUND

Tasmania was a major supplier to the world of 'osmiridium', produced from placer deposits during 1912 to 1925, at which point the production from the Witwatersrand surpassed that of Tasmania. The Os-Ir-Ru alloy grains were mined from alluvial and eluvial deposits associated with some of the ultramafic-mafic complexes in Western Tasmania.

The ultramafic-mafic complexes of western Tasmania have recently (Brown, in press) been recognised to consist of three different ultramafic rock successions. One of these three successions, a multiple intrusive layered pyroxenite-peridotite with associated gabbro (LPG) succession, which forms the Serpentine Hill Complex, has anomalously high PGE contents with respect to the other two; whilst a second, a layered dunite-harzburgite (LDH) succession, parts of which occur in the Heazlewood, Mt Stewart, Serpentine Ridge and Adamsfield areas, has associated 'osmiridium' deposits.

PGE minerals associated with the LDH succession have been studied by Twelvetrees (1914), Reid (1921), and Nye (1929), with a summary by Elliston (1965). Studies of the specific PGE mineralogy of these areas have been done by Cabri and Harris (1975) and Ford (1981), and a study of the PGE chemistry of the Serpentine Hill Complex (LPG succession) has recently been completed (Brown *et al.*, in prep).

It is usually considered that osmium and iridium are concentrated in the residuum of a first-stage melting phase and are then precipitated as an alloy phase in the resultant cumulates of the second stage melt. This consideration is consistent with observations in western Tasmania, where Os-Tr-Ru mineral grains are associated with areas of the LDH succession. Platinum, palladium and ruthenium are thought to be susceptible to the

degree of sulphur saturation of the liquid, and when this is high enough, sulphur minerals of Pt-Pd-Ru are formed. These minerals are usually associated with a fresh influx of late stage olivine-rich liquid associated with troctolite and anorthosite units in large stratiform complexes, as in the J-M Reef in the Stillwater Complex, Montana; and in the Merensky Reef in the Bushveld Complex in South Africa.

The Serpentine Hill Ultramafic-Mafic Complex is enriched in Pt, Pd, Ru, Rh, and Ir with respect to samples so far analysed from most other Tasmanian ultramafic-mafic bodies, indicating that the simplistic sulphide saturation model is not the only control of the PGE mineral formation. There are uncertainties in the behaviour and distribution of PGE in undepleted mantle rocks, during partial melting and in different environments of magma crystallisation, as well as an apparent original heterogeneous distribution of PGE in the mantle material (Page *et al.*, 1982). It is possible that when the Heazlewood River Ultramafic Complex is studied in detail, zones of PGE-rich chromitite, similar to those defined at Serpentine Hill (Brown *et al.*, in prep.), will be found.

"GEOLOGY AND PLATINUM-GROUP ELEMENT (PGE) GEOCHEMISTRY OF THE SERPENTINE HILL COMPLEX, DUNDAS TROUGH, WESTERN TASMANIA."

A.V. Brown, N.J. Page, and A.H. Love

*Abstract*

Field relations, petrology, and the platinum-group element (PGE) geochemistry of ultramafic and mafic rocks in the Middle Cambrian Serpentine Hill Complex indicate that it is an orthopyroxene-rich Alaskan-type complex and not a dismembered ophiolite, as previously described. The complex consists of multiple intrusions which formed an orthopyroxene-rich layered sequence, an olivine-rich sequence, and a gabbroic unit. The layered sequence is composed of thin repetitive units of serpentinised olivine cumulate and orthopyroxene cumulate, with minor olivine-orthopyroxene cumulate. Locally these units are plagioclase bearing. Primary structural features include unconformities, troughs, modal layering, slump structures, and syndepositional faults. The layered sequence is intruded by plagioclase-dunite which locally contains chromite-rich zones. The chromite ranges from 64 to 69 in Cr/(Cr+Al) and 37 to 46 in Mg/(Mg+Fe<sup>2+</sup>). In places, the plagioclase-dunite sequence is layered and contains cognate xenoliths of the orthopyroxene-rich layered sequence. The two ultramafic sequences are cut by variable grain-sized gabbroic rocks. The Pt content in rocks of the complex ranges from 17 to 60 ppb and is highest in the gabbroic rocks, which also have the highest Pd content (maximum 18 ppb). The ultramafic rocks of the layered and olivine-rich sequence contain no detectable Ir (<100 ppb) and less than 2 ppb Pd, in contrast to chromitites which contain up to 90 ppb Ir and 420 ppb Ru. Laurite and Os-Ir alloy occur in the chromitites. Comparison of chondrite-normalised PGE ratios of chromitites with those of ophiolite, stratiform, and komatiitic complexes shows distinct differences. Although the overall chondrite-normalised pattern shows relative enrichment in Ru and Ir relative to Pt and Pd, similar to patterns for ophiolitic chromitite, Pt is more enriched with respect to chondrite in ophiolites.

SUMMARY OF ULTRAMAFIC-MAFIC COMPLEXES

The ultramafic rocks of western Tasmania fall into three groups: A succession of Layered Pyroxenite-Dunite (LPD); a succession of Layered

Table 1. MEANS, STANDARD DEVIATION AND NUMBER OF UNQUALIFIED VALUES FOR INDIVIDUAL AREAS AND ROCK TYPES.  
NUMBER OF SAMPLES IN PARENTHESIS.\*

Area or Lithology	Pd	Pt parts per billion	Rh	Ru	Ir
Anderson Creek	<1	29.0 ± 10.3(4)	<1	<100	<20
Heazlewood River (northern part)	1(1)	16.0 ± 4.2(4)	<1	<100	<20
Heazlewood River (southern part)	<1	18.3 ± 2.3(6)	<1	<100	<20
Wilson River - Serpentine Ridge	1.3 ± .6(3)	16.2 ± 8.5(5)	6.5(2)	150(1)	40(1)
Wilson River - Riley Knob	1.5(2)	41.5 ± 2.1(2)	<1	<100	<20
Huskisson River - Lynch Hill	1(3)	16.3 ± 1.2(3)	1(2)	<100	<20
Huskisson River - 14 km Quarry	1(2)	22.5 ± 10.6(2)	2(1)	<100	<20
Serpentine Hill					
Orthopyroxene-rich sequence	1.7 ± .6(3)	36 ± 21.3(4)	2.0 ± 1.0(3)	<100	<20
Olivine-rich sequence	2.3 ± 1.6(9)	33.4 ± 16.1(12)	5.0 ± 2.8(6)	<100	<20
Gabbroic sequence	10.3 ± 6.1(4)	36 ± 19.6(4)	1(1)	<100	<20
Chromitites	3.4 ± 1.3(5)	44.5 ± 11.8(6)	6.2 ± 2.1(6)	270 ± 112(6)	68.3 ± 19.4(6)
Dunites	1.8 ± 1.8(5)	22.3 ± 11.6(6)	<1	<100	<20
Melba Flats	4.5 ± .7(2)	1240(1)	54(1)	180(1)	70(1)
Layered Dunite-Harzburgite	1.5(2)	13.7 ± 2.5(6)	1	<100	<20
Layered Pyroxenite-Dunite	1.1 ± .4(7)	23.6 ± 12.2(7)	1.3 ± .6(3)	<100	<20

\* Reproduced from Brown et al. (in prep.). Values calculated from data in Table 1 of Brown et al. (in prep.).

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Dunite-Harzburgite (LDH) and a succession of Layered Pyroxenite-Peridotite and associated Gabbro (LPG). These three ultramafic rock successions can be recognised by both field characteristics and mineral chemistry. Comparison of mineralogy and mineral chemistry with experimental work indicates that the ultramafic rocks formed at high temperatures and low pressures, the parental melt having low oxygen fugacity and a low water content. All three of the ultramafic successions are consistent with being cumulate bodies formed as crustal magma chamber products, each from one of the three different magma events found within the Eocambrian to Cambrian successions within the Dundas Trough.

The LPD succession is a monotonous, finely layered sequence containing orthopyroxene of  $En_{85-89}$ ; olivine of  $Fo_{87-89}$ ; minor chrome diopside (Ca:Mg:Fe=47:49:4), and chrome spinel with an average  $100 \times Cr/(Cr+Al)$  ratio of 65 and a variable  $100 \times Mg/(Mg+Fe^{2+})$  ratio with an average of 43.

The LDH succession is well layered, contains a tectonic foliation parallel to layering, the result of flattening of the mineral grains, and contains olivine of  $Fo_{93-94}$ ; orthopyroxene of  $En_{93-94}$  with very low to undetectable  $Al_2O_3$  and CaO contents. Chrome spinel grains have a  $100 \times Cr/(Cr+Al)$  ratio of 87-89 and a variable  $100 \times Mg/(Mg+Fe^{2+})$  ratio with an average of 49.

The physical features of the LPG succession are described in the abstract to Brown *et al.* (above). No relic olivine cores were encountered; orthopyroxene is  $En_{86-87}$ , chrome diopside (Ca:Mg:Fe=48:48:4), and there are two compositions of chrome spinel. Within the ultramafic rocks chrome spinel has a  $100 \times Cr/(Cr+Al)$  ratio with an average of 60, and an  $100 \times Mg/(Mg+Fe^{2+})$  average ratio of 48. In the chrome-rich zones within the olivine-rich sequence, spinel grains have an average  $100 \times Cr/(Cr+Al)$  ratio of 69 and an average  $100 \times Mg/(Mg+Fe^{2+})$  ratio of 40. The gabbroic phase is a two-pyroxene gabbro with a variable grain size and texture.

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## APPENDIX 1

### Ultramafic rock successions

This appendix is taken from a draft edition of Geological Survey Bulletin 62.

## ULTRAMAFIC ROCK SUCCESSIONS

## Introduction

Three different ultramafic rock successions have been recognised within the study area. The successions can be recognised either by field characteristics and/or mineral chemistry. The three groups are a high-magnesium layered dunite-harzburgite succession, which contains a tectonic fabric formed by plastic deformation of cumulate layers; a layered pyroxenite-dunite succession, which is dominated by orthopyroxene; and a multiply intrusive ultramafic-gabbro succession. Other areas of ultramafic rocks in Tasmania can be successfully correlated with this grouping.

Five of the fifteen well-known areas of ultramafic-mafic rocks within Tasmania are included in the area mapped; these are the Mt Stewart, Wilson River, Huskisson River, Serpentine Hill and Dundas complexes (areas 4 - 8, fig. 42). A sixth area, the Heazlewood River complex (area 3, fig. 42) occurs in the area covered by reconnaissance mapping to the north of the Corinna Road.

The largest volume of ultramafic rocks consists of well-layered dunite, orthopyroxene-bearing dunite and harzburgite. This is termed the Layered Dunite-Harzburgite (LDH) succession. This succession is relatively uniform in composition, and contains a foliation parallel to layering defined by primary mineral alignment of orthopyroxene and chrome spinel grains as well as later flattening and elongation of olivine grains. The second succession is also well layered, but is dominated by orthopyroxene. The main rock types are orthopyroxenite, olivine orthopyroxenite, and dunite. No harzburgite is found in this succession. This sequence is called the Layered Pyroxenite-Dunite (LPD) succession. As well as the uniform layering, another significant feature of both of the above successions is the apparent lack of feldspar as a mineral constituent. Plagioclase or hydrogarnet after plagioclase were not observed in any rocks from the LDH or LPD successions or correlates in either the study area or at Adamsfield. The only location at which plagioclase is known to occur within the ultramafic successions is in the Serpentine Hill and Heazlewood River complexes.

The third subdivision is characterised by multiple intrusions of various ultramafic and mafic rock types. The first part of this third group is similar to the LPD succession in that it is a well-layered sequence dominated by orthopyroxenite with subsidiary olivine pyroxenite and dunite, but differs from the LPD succession in that the sequence contains numerous sedimentary-like structural features and delayed mineral grading in the upper part of the dunite layers. The second phase is dominated by plagioclase-bearing dunite which contains zones enriched in chrome spinel. The third phase consists of multiple intrusions of two-pyroxene gabbro. The plagioclase dunite magma intruded and brecciated the dominantly pyroxenite sequence and the gabbro intrudes both of the ultramafic phases. This succession is termed the Layered Pyroxenite-Peridotite and associated Gabbro (LPG) succession.

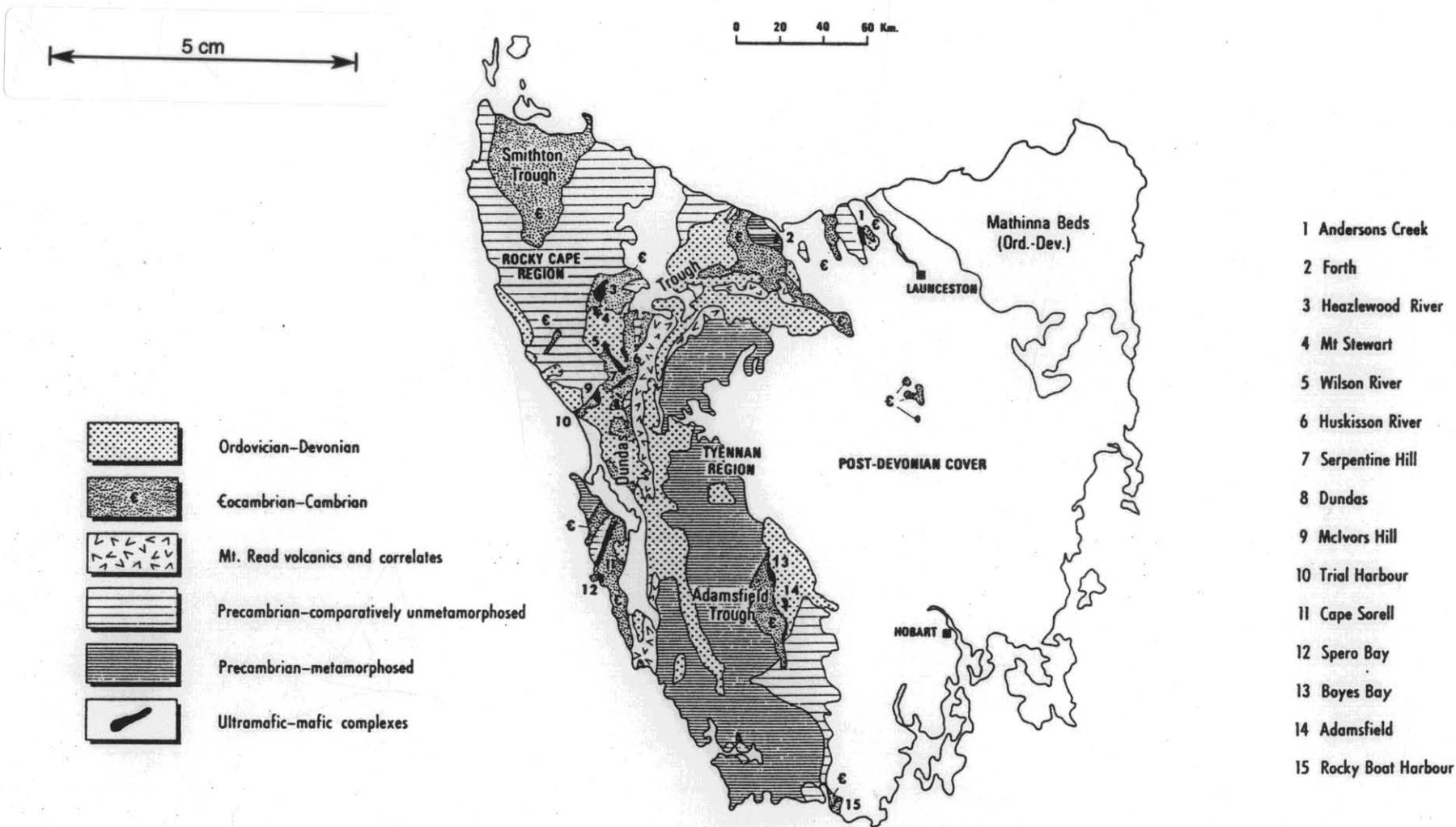


Figure 42. Schematic geological map of Tasmania showing location of ultramafic-mafic complexes  
 Rock distribution after Williams (1976) Structural map of Pre-Carboniferous Rocks of Tasmania, Department of Mines, Tasmania.

The LDH succession and correlates form the western side of the Heazlewood River Ultramafic Complex, the "Nineteen Mile Creek Dunite" of Rubenach (1973); occupy the whole of the Mt Stewart complex; and occur as the major part of the Wilson River and Huskisson River Ultramafic Complexes. They are also known to form a large part of the Adamsfield and Boyes River Ultramafic Complexes (area 13 - 14, fig. 42). The LPD succession is found as fault-bounded blocks intermixed or juxtaposed with areas of the LDH succession in the northern (Harman River) and southern (Riley Knob) parts of the Wilson River Ultramafic Complex; near Lynch Hill in the Huskisson River complex (fig. 43); and forms the Colebrook Hill and Dundas bodies. Another area of LPD succession occurs at Adamsfield, where rafts within sheared serpentinite sheaths are fault juxtaposed with areas of LDH succession (Brown, 1972; Varne and Brown, 1978). The multiply intrusive LPG succession has so far only been observed at Serpentine Hill and to the east in the Kapi Creek - Ring River area, but is thought to also occur as part of the Heazlewood River Complex.

The only part of the Heazlewood River Ultramafic Complex (Rubenach, 1973) examined in detail during this study was the southernmost tail of the complex to the south of Corinna Road and to the west of the areas of Cba and Cbm (fig. 2). This area contains a sequence of layered orthopyroxenite and olivine orthopyroxenite which has chemical and petrographic characteristics similar to rocks of the LPD succession. The area was examined to facilitate the mapping and chemical separation of basaltic pyroxenite (Cbap) from ultramafic pyroxenite (Esp) (fig. 2). Rubenach (1973) subdivided the Heazlewood River Ultramafic Complex into the "Nineteen Mile Creek Dunite", which is a correlate of the LDH succession; and the "Caudry Hill Pyroxenite" and "Brassey Hill Harzburgite", both of which consist of interlayered peridotite and pyroxenite with plagioclase. The following descriptions of the different successions, especially the relationships exposed in the Serpentine Hill area, show that remapping of the Heazlewood River Complex is required before any correlation is made for these plagioclase-bearing sequences.

Interpretation of the ultramafic rocks of Tasmania has been much debated in the past. Their importance in tectonic models at times has been over-emphasised, and often misinterpreted, due to lack of factual information as to the nature of the different complexes. One of the most important features of the ultramafic rocks of western Tasmania is their size, or lack thereof. The ultramafic rocks of the Heazlewood River complex crop out over an area of approximately 32 km<sup>2</sup>; those of the Mt Stewart complex over approximately 7.5 km<sup>2</sup>; the Wilson River complex 27 km<sup>2</sup>; at Huskisson River 6.5 km<sup>2</sup>; Colebrook Hill less than one km<sup>2</sup>; at Dundas three km<sup>2</sup>; the Kapi Creek - Ring River area 2.5 km<sup>2</sup>; and at Serpentine Hill two square kilometres.

The Adamsfield complex covers five square kilometres and the Boyes River body crops out over 15 km<sup>2</sup>. In total, ultramafic rocks only occupy approximately 80 km<sup>2</sup> of nearly 1000 km<sup>2</sup> of the Dundas Trough studied. The term 'complex' is used for an area of any size which contains ultramafic rocks belonging to one or more of the three recognised successions which occur on the West Coast of Tasmania, and not in the sense of a large area of genetically related

ultramafic-mafic rocks, as for example those found in the classical ophiolite complexes of eastern Europe.

Chemical analyses of bulk rock samples and electron probe analyses of mineral constituents of the different rock types in the various successions were obtained to allow chemical classification of the three successions. The results are included in tables in Appendix 4. The area chosen to chemically characterise the LDH succession was the Harman River area at the northern end of the Wilson River complex; that for the LPD succession as the Riley Knob area at the southern end of the Wilson River complex; and the Serpentine Hill area was used for the multiply intrusive LPG succession.

The physical and petrographic features of the different areas of ultramafic rocks will be discussed under their geographic associations and then the chemical characteristics of the three different successions will be considered.

Figures 1 to 3 show that the ultramafic rocks lie along a general north-south trending elongate 'S' shaped area. Their present position and relationships with surrounding rocks are the result of Devonian deformation, as can be seen by the position of the Wilson and Huskisson River complexes. Although the whole of the western margin of the Wilson River complex is in contact with the Eocambrian Crimson Creek Formation, the eastern margin is in contact with rock types which vary from those belonging to the fossiliferous Cambrian Huskisson Group, the Ordovician Gordon Limestone correlate, and the Silurian Crotty and Amber Formation correlates (fig. 1). The intrusion of the Meredith Granite (circa 350 Ma) replaced an eleven kilometre long section which would once have formed a continuous belt of ultramafic material from south-west of Serpentine Hill to north-west of Bronzite Hill (fig. 3). The Meredith Granite also metamorphosed the ultramafic rocks around the contact margins, as well as around high level intrusions in the Harman River and Mt Stewart areas, indicating that the ultramafic rocks had been re-emplaced into their present position before the Devonian granitic event.

Evidence exists in the basal conglomerate units of the Dundas Group that some ultramafic rocks had been emplaced into the basin of deposition of the Dundas Group, as detritus from these ultramafic rocks is included in the Red Lead Conglomerate at the Razorback mine workings (Padmasiri, 1974) and at Confidence Saddle (Rubenach, 1974; this study). Similar evidence of a Cambrian emplacement age for the ultramafic successions into basins of active deposition also occurs at Adamsfield (Carey and Banks, 1954; Banks, 1962b).

In the following descriptions, the terminology used to describe the ultramafic rocks follows Irvine's (1982) modification of Jackson (1967) and Wager, Brown and Wadsworth (1960).

## Wilson River Ultramafic Complex

The Wilson River Ultramafic Complex lies on the western side of the Huskisson Syncline. The northern extent of this 17 km long body is in contact with the Meredith Granite in the upper Harman River area, where it is approximately three kilometres wide. The southern extent crops out in the Pieman River around CP718739, where it is approximately 500 m wide. The northern six kilometres along strike of this complex is dominantly composed of LDH succession rocks but also includes two small areas occupied by infaulted blocks of LPD succession (fig. 43). The middle zone of seven kilometres (Serpentine Ridge) consists entirely of LDH succession rocks, whereas the southern four kilometres, between Riley Knob and the Pieman River, is dominantly of LPD succession with minor blocks of LDH succession material surrounded by sheared serpentinite. Earlier studies of this area are found in Waterhouse (1914), Reid (1921) and Taylor (1954, 1955).

### Harman River area

At the northern end of the Wilson River complex, in a three kilometre diameter area around CP625865, the layered nature of the LDH succession is well exposed. Rocks belonging to the LDH succession are now known to occupy the majority of this area (fig. 43) and not just the western side, as shown in Figure 1. The interlayered dunite, orthopyroxene-bearing dunite and harzburgite, depending on the content of orthopyroxene in any specific layer, vary in thickness between 25 mm and 400 mm with an average of approximately 150 mm. The rocks are composed of three mineral types, namely olivine, enstatite and chrome spinel.

The dunite layers are considered to have been cumulates with sharp phase contacts with adjacent layers. Chrome spinel occurs as a subsidiary mineral phase in varying proportions from one to five per cent, and in some places is present in a higher concentration and forms a mineral foliation. The harzburgite and pyroxene-dunite layers have both olivine and orthopyroxene as cumulus phases, with the orthopyroxene crystals being fairly uniform in size. Chrome spinel is an accessory phase in both pyroxene-dunite and harzburgite but is less common than in dunite layers (being approximately one per cent) and does not form mineral foliations.

Across a two kilometre traverse from the granitic rocks on the western margin [CP608868] eastwards to the northernmost area of LPD succession [CP627863] (fig. 1), the percentage of harzburgite increases to the east. The western part of the area consists of interlayered dunite with thin, subordinate pyroxene-bearing dunite. After 100 - 150 m harzburgite layers enter the succession, the formation of pyroxene-dunite or harzburgite only depending on the amount of orthopyroxene present in any specific layer. By half-way, the succession consists mainly of harzburgite, in layers between 100 mm and 400 mm thick, with dunite in 10 mm to 50 mm layers. Over the eastern 750 m of the traverse, the succession is dominantly harzburgite with thin interlayers of dunite.

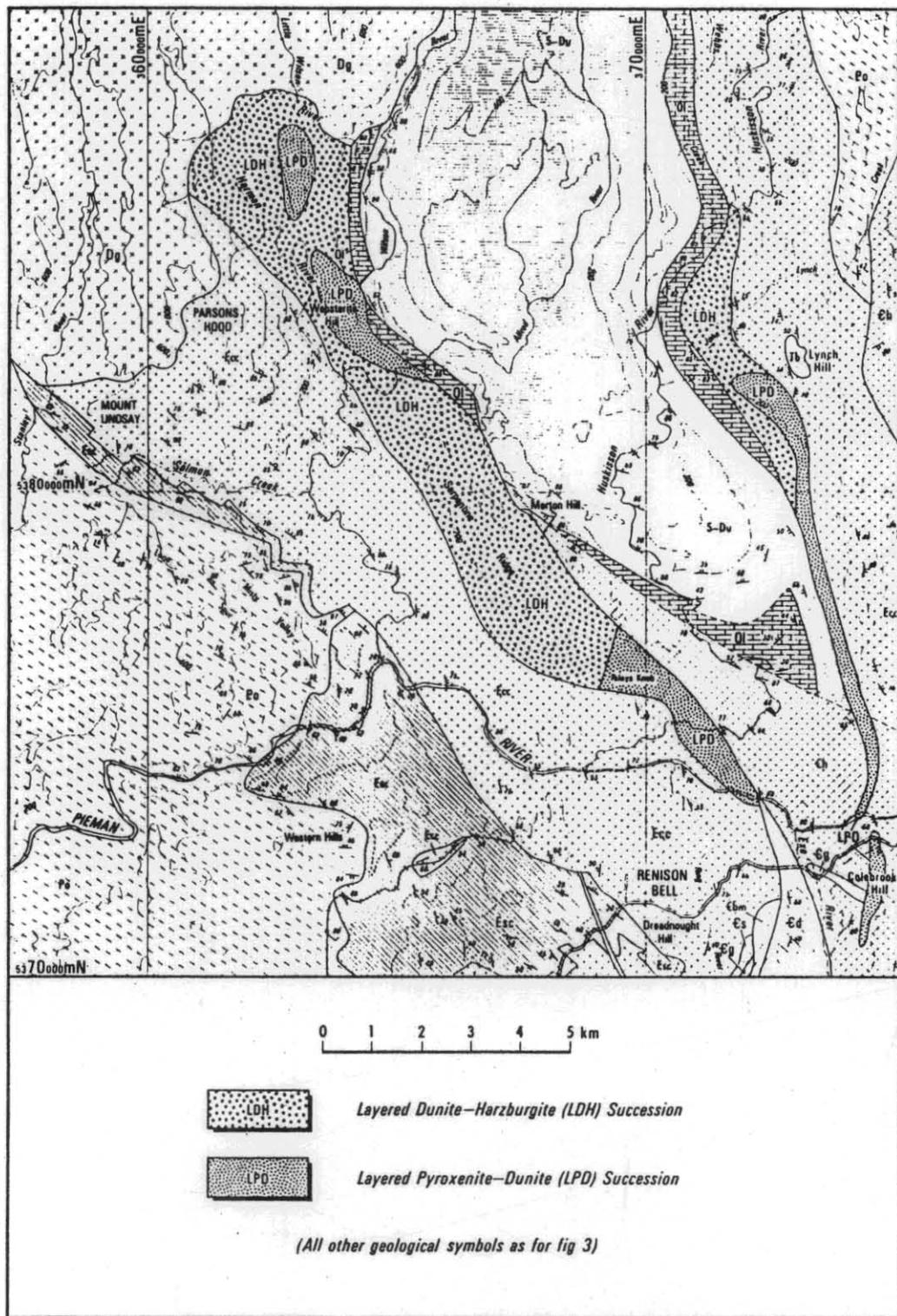


Figure 43. Distribution of areas of LDH and LPD succession ultramafic rocks in the Renison Bell-Mt Ramsay area.

Occasional boudinaged lenses and irregularly shaped veins or dykes of late stage coarse-grained orthopyroxenite occur throughout the succession. The lenses vary from 500 - 600 mm in length and up to 75 mm thick, to three to five metres in length and 100 - 150 mm thick. The lateral extent of the lenses is unknown, and the orientation of the lenses and dykes is subparallel to layering.

The enstatite crystals are tabular and elongate in the plane of bedding in both the pyroxene-dunite and harzburgite layers but are not aligned in any specific direction within this plane. Where the percentage of pyroxene crystals in any specific layer is low, the crystals form a mineral foliation rather than a specific continuous layer.

In thin section, the degree of serpentinisation is such that in dunite and pyroxene-bearing dunite samples the original texture cannot be unambiguously interpreted, and in harzburgite samples no relict silicate mineral cores remain. In the dunite and pyroxene dunite samples, olivine grains are now remnant cores (ranging in size from 0.20 - 0.65 mm but usually between 0.35 - 0.45 mm) of fresh olivine surrounded by a mesh of serpentine group minerals (lizardite with minor chrysotile). If adjacent cores with uniform extinction are taken as an original olivine crystal, then many grains have straight crystal boundaries parallel to extinction. In many cores optical deformation lamellae parallel to (100) occur. Kink bands parallel to (001), as observed in similar rocks from the Adamsfield area (Varne and Brown, 1978), were not found in any samples from the Harman River area.

The closely associated aggregates of remnant cores with uniform extinction indicate that the majority of crystals in these rocks were between two and four millimetres in length, with some crystals being up to five millimetres. Some of the larger grains are now wedge-shaped and elongate in the direction of layering. The strong, probable Devonian tectonic foliation found in the surrounding serpentinite sheath is also seen in samples from within the rafts of layered material. In thin section, the foliation produces a spaced fracture 0.3 - 0.45 mm apart at an angle of 10 to 25 degrees to the mineral foliation (layering). In some samples, this later foliation produces a crenulation cleavage or kink band effect which persists across all grains cut by the foliation.

Where orthopyroxene grains are present they define a mineral foliation parallel to layering. Some grains contain kink bands. In some dunite samples, trains of fractured euhedral chrome spinel grains (0.25 - 0.75 mm) form a mineral foliation which is also parallel to layering. The coarse-grained pyroxenite lenses and dykes are boudinaged and consist of interlocking grains of orthopyroxene, ranging in size from 0.5 - 5 mm and which contain undulose extinction. Zones of fracturing and brecciation occur through these grains, but no recrystallisation has occurred.

No evidence of a protogranular or porphyroclastic texture (Mercier and Nicolas, 1975) was found in any sample collected from this succession. The overall evidence is consistent with a well-layered

cumulate succession which has undergone plastic to solid state deformation (Raleigh, 1967; Carter and Ave'Lallement, 1970) without distortion of the layering during tectonic dismembering and emplacement of the succession into basins of deposition prior to the middle Middle Cambrian.

The western margin of the northernmost block of LPD succession with the LDH succession [between CP629861 and CP630870] is a zone of cataclasis, indicating a faulted contact and not a continuous sequence. This block contains thin layered orthopyroxenite, of varying grain size, interlayered with serpentinitised orthopyroxenite and minor dunite. The area to the north of this block, around CP635874, consists of serpentinitised and contact metamorphosed LDH succession.

Along the fault zone between the two successions [around CP629863] samples from the zone of cataclasis have undergone recrystallisation to amphibole minerals, probably due to this area being within the aureole of a high-level granitic intrusion. In the layered part of the LPD succession raft, both pyroxenite and olivine pyroxenite layers contain relict primary minerals but the dunite samples are totally serpentinitised. The pyroxenite samples have either an even-grained or interlocking adcumulate texture, with grains ranging in size from 0.5 - 5 mm. The larger grains contain sweeping extinction and fracture zones. No recrystallisation of the fracture material has occurred. Olivine pyroxenite samples contain 0.5 - 0.75 mm olivine grains which are poikilitically enclosed by one to three millimetre orthopyroxene grains, most of which contain undulose extinction.

In the areas around CP625867 and CP630850 (fig. 1), high level granitic intrusions have metamorphosed the serpentinite into an equigranular metadunite which resembles a slightly metamorphosed coarse-grained sandstone in both hand-specimen texture and colour. Another block of LPD succession occurs to the east and south of the latter area of metadunite, the highest point of which is Websterite Hill (fig. 43).

In thin section, metadunite samples have an equigranular mosaic texture. The average grain size varies between 0.45 mm and 0.7 mm with coarser-grained samples having grains up to 1.35 mm across, and finer-grained samples down to 0.25 mm. Many olivine grains, in lower-grade samples, have a pleochroic light to dark orange-brown colour and enclose dusty magnetite throughout the whole grain. In higher-grade samples, the orange-brown colouration disappears and the dusty magnetite has coagulated to form small (0.01 mm) magnetite grains. In some samples, areas up to 4.5 mm by 2.75 mm containing a mosaic of 0.35 - 0.45 mm grains have a common extinction.

Sheaves of a colourless acicular mineral with very high relief occur between and around isolated olivine grains and probably represent amphibole minerals after serpentinitised orthopyroxene. Primary chrome spinel grains usually show alteration around their edges and are ubiquitously subhedral. Minor post-Devonian serpentinitisation has occurred along cracks and fractures within these samples.

### Serpentine Ridge area

The seven kilometre long Serpentine Ridge is a strike ridge of interlayered dunite, pyroxene-bearing dunite and harzburgite belonging to the LDH succession. The proportion of harzburgite in the succession increases from west to east. Most of this ridge consists of serpentinite after the respective rock types, but layering, euhedral to subhedral chrome spinel stringers and foliations, and the variation in percentage of pyroxene in different layers, is easily observed in outcrop.

In the southern part of this zone, to the south of the Lower Pieman Dam Road and between Sweeney and Riley Creeks (fig. 1), an area of outcrop exists where some samples contain relict cores of olivine. The samples have a similar texture to those from the Harman River area, and contain flattened and elongated olivine grains up to five millimetres in length (based on mutual extinction of adjacent cores) with both disseminated euhedral (0.15 - 1.0 mm) and two to three millimetre trains of fractured anhedral spinel grains.

Along the eastern margin of the body, in Sweeney Creek, the sheared serpentinite sheath contains small blocks of LPD succession pyroxenite (identified by mineral chemistry), which in thin section contains an even-grained adcumulate texture and consists of 1.7 - 7.0 mm grains of orthopyroxene with minor 0.2 - 0.25 mm euhedral chrome spinel which is both enclosed by and occurs along the grain boundaries between the pyroxene grains. Concentrations of chrome spinel also occur in the dunite along the southern part of the ridge, which was once an alluvial osmiridium working area. One chrome spinel nodule (75 x 50 x 50 mm) was recovered, and analysis revealed a high concentration of Platinum Group Elements in comparison to whole rock samples, rich in disseminated spinel, from this succession (Brown et al., in prep.). Further north [around CP670791] occur small lenses (200 mm long by 5 mm thick) and zones enriched in disseminated chrome spinel forming a mineral foliation.

### Riley Knob Area

To the south of Serpentine Ridge, the four kilometre section between Riley Knob [CP689764] and the Pieman River contains dominantly LPD succession material, with large blocks of coarse-grained orthopyroxenite in sheared serpentinite from the LDH succession, cropping out in the Huskisson River along the eastern margin of the ultramafic body.

An excellent section of LPD succession crops out in the vicinity of Riley Knob. The outcrop consists of thin, uniform layers of orthopyroxenite, olivine orthopyroxenite and dunite. Harzburgite has not been found in this succession. The layered ridges in this area are surrounded by sheared serpentinite and each of the layered rafts is orientated so that its strike is in the direction of the dominant regional foliation and the layering is either vertical or dips steeply to the east, as is also the case with the regional foliation.

Orthopyroxene layers dominantly vary in thickness between 1 to 2 mm and 150 mm, the majority being less than 20 mm thick with occasional layers between 20 mm and 150 mm in thickness. Olivine orthopyroxenite layers mainly vary between 1 to 2 mm and 20 mm in thickness, the majority being less than or equal to 5 mm. An occasional layer is found between 20 mm and 100 mm thick. The majority of dunite layers are also between 1 to 2 mm and 20 mm in thickness, with layer thickness being evenly divided between very thin (less than 5 mm) and thin (6 - 20 mm). The number of dunite layers between 20 mm and 200 mm in thickness is small, but exceeds the number of orthopyroxenite layers of this thickness.

As in other areas of LPD succession sampled, the dunite layers are now completely serpentinitised, but these layers always carry a higher percentage of chrome spinel grains (0.14 - 0.36 mm) than the dominantly pyroxenite layers. Olivine pyroxenite samples have either an even-grained granular or interlocking texture and consist of approximately 85 - 90% orthopyroxene, 1 - 2% clinopyroxene 1 - 2% chrome spinel, and up to 10% olivine. The olivine grains, ranging in size from 0.45 to 1.35 mm, normally occur between orthopyroxene grains, but some are partially enclosed by postcumulus overgrowths on orthopyroxene with an occasional sample having olivine grains poikilolitically enclosed by orthopyroxene. Orthopyroxene grains range in size from 0.45 to 2.25 mm, the larger grains containing kink bands and/or fine exsolution lamellae of clinopyroxene. Diopside occurs as individual anhedral grains (0.14 - 0.23 mm across) and occupies areas between orthopyroxene grains. In some samples clinopyroxene also occurs as stringers of exsolution blebs along cleavage planes within orthopyroxene grains.

The orthopyroxenite layers are dominantly of an even-grained adcumulate texture but some interlocking textured samples exist. The grain size varies from 0.45 to 4.5 mm in most samples. Minor intergranular diopside and accessory chrome spinel (0.2 - 0.4 mm) occur along boundaries between orthopyroxene grains within these samples. An occasional spinel grain is enclosed by orthopyroxene. Some of the larger orthopyroxene grains contain stringers of clinopyroxene blebs or thin exsolution lamellae along the cleavage planes.

Due to lack of continuous outcrop, the presence or absence of cyclic layering could not be ascertained. One section of 259 layers was measured (table 13) and shows that the layered sequence contains rhythmic layering. The dominant rhythm is dunite to orthopyroxenite to dunite to orthopyroxenite (45% of layers), followed by dunite to orthopyroxenite to olivine orthopyroxenite to orthopyroxenite (24% of layers). All contacts are sharp phase contacts, and no size or mineral grading was observed in any layer. The classical three-state rhythm, dunite to olivine orthopyroxenite to orthopyroxenite, found in many stratiform complexes, only occurs on four occasions in this sequence.

Mt Stewart Ultramafic Complex

The Mt Stewart Ultramafic Complex (area 4, fig. 42; fig. 2) is composed of thick dunite layers with thin interlayered pyroxene-dunite of the LDH succession. Harzburgite layers are rare in this area. The southern half of the complex is underlain and surrounded by intrusions of the Devonian Meredith granitic body. The northern half is in faulted contact with a sedimentary rock succession which has been correlated with the Success Creek Group (Csq, fig. 2). To the north-east of the complex is a small area of high-magnesian andesite flows (Cba, fig. 2), and bodies of basaltic pyroxenite occur further along the north-eastern margin. Some of these bodies are highly metamorphosed by the underlying granitic rocks [around CQ585027] and now consist of mainly amphibole minerals, whereas other areas [around CQ608025] are highly weathered.

Numerous late stage coarse-grained and very coarse-grained orthopyroxenite dykes and veins cut the succession throughout the area. In thin section, samples of these dykes consist of large (3 - 5 mm) grains with an interlocking texture but which contain a high strain, undulose extinction and kink bands. Chrome spinel grains one to two millimetres in size are enclosed by the orthopyroxene grains and these spinel grains in turn enclosed original silicate grains which are now serpentine group minerals.

Dunite and pyroxene-dunite samples contain the same texture, grain size and deformation characteristics as similar samples from the Harman River area. The enclosed chrome spinel grains are generally larger, and a greater percentage of grains enclosed or partially enclosed earlier silicate minerals which are now replaced by serpentine group minerals. Numerous areas contain high concentrations of chrome spinel grains, one such area being enriched in disseminated pods up to 5 mm across (around CP590998; fig. 2).

Metadunite samples, as well as partially metamorphosed residual serpentinite, have similar textures to similar samples from the Harman River area. One feature which persists throughout many samples of metadunite is the 4 mm to 5 mm areas of 0.2 - 0.35 mm recrystallised olivine grains which have a common extinction.

Earlier literature on this area can be found in Reid (1921) and Rubenach (1973).

Huskisson River Ultramafic Complex

The Huskisson River Ultramafic Complex is an irregularly shaped area of ultramafic rocks on the eastern side of the Huskisson Syncline. Rocks of the Crimson Creek Formation occur along its eastern margin and the Ordovician Gordon Limestone correlate occurs along the south-western margin from north of the Lower Pieman Dam Road to the south where outcrop ceases beneath glacial outwash sediments (fig. 1). The northern extent is traversed by the Huskisson River around CP719759 (fig. 1), where the rocks consist of sheared serpentinite and blocks of LDH succession. The southern extent crops out as small

isolated areas of sheared serpentinite with blocks of LPD succession, from south of CP710830 (fig. 1) to the Pieman River.

This complex, as with the Wilson River Complex, is a mixture of material from both the LDH and LPD successions. The majority of the area north and south of John Lynch Creek is known to be serpentinite after LDH succession (based on the mineral chemistry of remnant chrome spinel grains). One area of LDH succession occurs around CP728817, approximately one kilometre south-west of Lynch Hill [CP731826]. This area contains interlayered orthopyroxenite, olivine orthopyroxenite and subordinate dunite. Layers are between 5mm and 10mm in thickness. The texture and mineralogy of the layers are similar to the material at Riley Knob, having both even-grained and interlocking adcumulate textures. Orthopyroxene grains are between 1 mm and 5 mm across, clinopyroxene between 0.2 mm and 0.4 mm, and chrome spinel grains 0.1 mm and 0.15 mm. The only sample which contained exsolution lamellae of clinopyroxene in orthopyroxene and kink bands in the larger grains was a very coarse-grained (8 - 30 mm) orthopyroxenite.

The Wilson River and Huskisson River complexes are most probably joined beneath the Huskisson Syncline. This high probability of connection is based on information contained in a detailed aeromagnetic survey carried out in 1981 (R. G. Richardson, pers. comm.; Corbett et al., 1982).

Colebrook Hill Ultramafic body

The small area of ultramafic rocks cropping out along the western side of Colebrook Hill is composed of sheared serpentinite enclosing irregular pods of remnant LPD succession material. From the knoll at CP747721 (fig. 1), north to the main road, the dominantly serpentinite body has been subjected to contact metamorphic effects. Remnant layering can be observed in some areas and pods of orthopyroxenite with chemical affinities to the LPD succession occur around CP746728 (fig. 1).

Ring River - Kapi Creek area

The zone of ultramafic and gabbroic rocks in the Kapi Creek - Ring River area contains a high degree of shearing. The zone is composed of sheared serpentinite with blocks of remnant layered ultramafic material intruded by gabbroic rocks. The gabbroic rocks are the result of multiple intrusions, as there are chilled margins in the gabbro, both against areas of ultramafic rocks and other areas of gabbro where one dyke has intruded another. This area has been metamorphosed by the underlying and cross-cutting granitic rocks, and most of the rocks of this zone are highly altered. To the north-west of the main gabbroic area (fig. 1), blocks of ultramafic rocks within sheared serpentinite contain remnant textures suggesting that some of the ultramafic rocks originally contained post-cumulus plagioclase, and that the parent rock was probably a plagioclase dunite, as found in the Serpentine Hill complex. Other areas of blocky serpentinite

indicate that the original rock types were layered. Some of the layers, on the basis of the disseminated chrome spinel content, were dunite, while other layers, on the basis of bastite pseudomorphs, were pyroxenite.

The northern extent of this zone, in Colebrook Creek [CP721708, fig. 1], contains kink-banded pyroxenite pods in a sheared serpentinite. This area has also been intruded by later gabbroic rocks. Textural features found within the rocks throughout this zone suggest that they are an extension of the Serpentine Hill complex.

### Serpentine Hill Ultramafic Complex

The Serpentine Hill Ultramafic Complex (fig. 2, 44) consists of fault-disrupted blocks of multi-phase ultramafic-gabbroic sequences and is exposed through a fault window between an area of the Eocambrian basic volcanoclastic succession, to the north and west, and fossiliferous middle Middle to Late Cambrian sequences to the south and east. The basaltic rocks immediately to the south-west of the complex belong to the low-titanium tholeiitic phase and interdigitate with basal conglomerate units of the fossiliferous Cambrian succession.

The first ultramafic unit to form was an orthopyroxene-rich layered sequence which was later intruded and dismembered by a magma which produced an olivine-rich sequence. Both of these sequences were in turn intruded by a two-pyroxene gabbro (fig. 45).

### Orthopyroxene-rich sequence

The layering in the orthopyroxene-rich sequence consists of a variety of alternating rock types. Due to the brecciated nature of this sequence no data on cyclicity in layering variation could be obtained. The layers are formed from varying proportions of olivine and orthopyroxene cumulates, which in places have feldspar as a post-cumulus phase. There are four main variations within the layering which are defined by mineralogy and grain size. In the first variation, the lower 5 - 10 mm of a layer consists of olivine and minor chrome spinel followed by a sharp but discontinuous boundary into a 25 - 50 mm thick zone where orthopyroxene joins olivine as the cumulus phase. The orthopyroxene crystals can be up to 1 - 2 mm across. A sharp boundary separates this upper zone from the overlying layer where orthopyroxene alone is the cumulus phase. The orthopyroxenite layers are between 50 mm and 100 mm thick.

The second variation consists of very thin layers (from less than 5 mm up to 20 mm, with an occasional 50 - 60 mm layer), which are marked by sharp contacts and are composed of olivine, olivine and orthopyroxene in different proportions, and orthopyroxene cumulates. In any section an orthopyroxenite layer separated two, three or four combinations of the other layer types.

A third variation occurs as 100 - 200 mm thick layers of harzburgite

containing stubby orthopyroxene crystals with a uniform 8 - 10 mm cross-section and minor feldspar as a post-cumulus phase, followed by a 20 - 50 mm thick layer of feldspathic orthopyroxenite. The orthopyroxene grains are usually 4 - 5 mm across and the feldspar makes up between 30 and 50 per cent of the layer. It is within this layer variation that unconformities and scours are common.

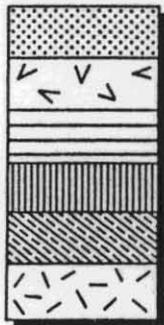
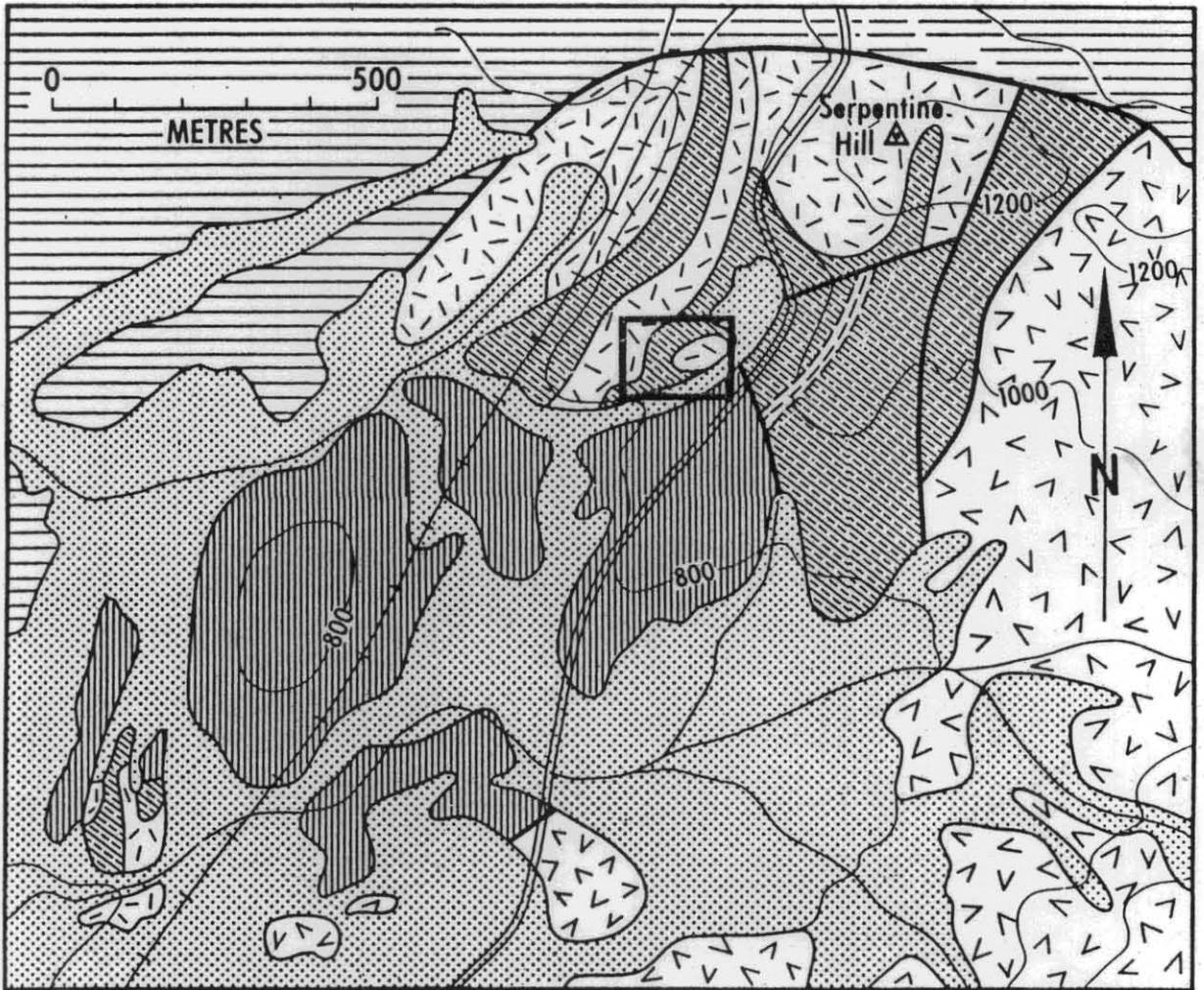
The final variation occurs within orthopyroxenite, with layers being defined by grain size differences. Contacts are sharp and within any specific layer the grain size is consistent. All the above layers also contain 1 - 2 per cent disseminated chrome spinel grains.

Numerous primary features are found within the orthopyroxene-rich sequence and include unconformities, troughs, modal layering, slump structures and syndepositional faults. Some angular discordance between layers appears to have been formed by scouring, as the infilling layers contain cross-bedding and reverse grading. The cross-bedding is defined by thin, flow-aligned crystal layers and lamination. Where olivine-rich lenses are observed cross-cutting underlying layers, they usually contain a thin (1 - 2 mm) basal zone with a very high concentration of chrome spinel grains, again indicating flow of crystal mushes.

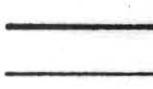
Syndepositional soft-sediment faults are shown by the sharp basal steps in the overlying layer, and the intraformational disruption of some zones within an otherwise well-layered succession indicates probable slumping. Channels up to 200 mm deep occur in some orthopyroxene layers. These channels are infilled by alternating laminae, between 10 mm and 25 mm thick, of olivine and orthopyroxene grains.

Very few of the primary minerals remain, because of the serpentinisation of the sequence. In thin section, olivine cumulate layers now contain serpentine minerals (dominantly lizardite), magnetite and spinel. The olivine-orthopyroxene layers have only minor remnant orthopyroxene grains within a serpentinitic matrix. The majority of orthopyroxene samples display some cataclastic deformation and have undergone partial recrystallisation, resulting in a serpentinised protoclastic texture. The large orthopyroxene grains are 7 - 8 mm in length and the surrounding recrystallised grains 0.5 mm across. Other samples have a mosaic adcumulate texture, with the orthopyroxene grains ranging in size from one to ten millimetres. Minor intergranular anhedral clinopyroxene occurs in these samples as well as clinopyroxene exsolution lamellae and blebs within the large orthopyroxene grains.

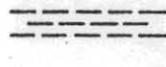
Websterite samples contain 7 - 8 mm long grains of orthopyroxene which enclose euhedral chrome spinel grains (0.01 - 0.15 mm). Clinopyroxene grains are between 3 mm and 5 mm across, some contain simple twins, and other grains have orthopyroxene exsolution lamellae. The texture varies between mosaic adcumulate and protoclastic. In feldspar-bearing orthopyroxene samples the pyroxene grains are usually stubby and 3 mm to 5 mm across. The feldspar has been altered to hydrogarnet.



Recent alluvium  
 Middle Cambrian low-titanium tholeiite  
 Eocambrian volcanoclastic lithicwacke-mudstone succession  
 Intrusive two-pyroxene gabbro  
 Dominantly intrusive and layered olivine-rich sequence  
 Dominantly layered orthopyroxene-rich sequence



Fault  
 Approximate geological boundary



Zone of chrome spinel concentration



Area covered by fig. 45

Figure 44. Geological map of the Serpentine Hill Ultramafic-Mafic Complex.



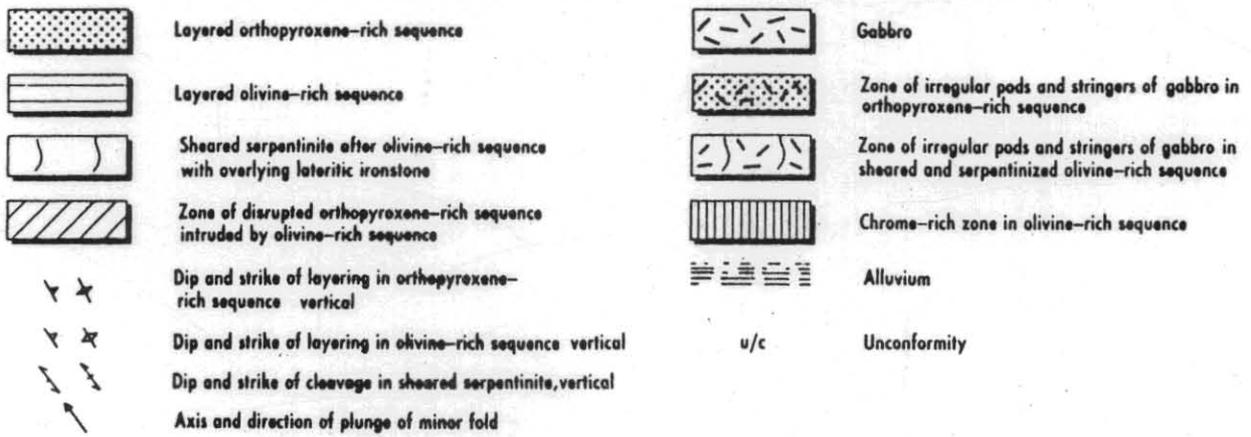
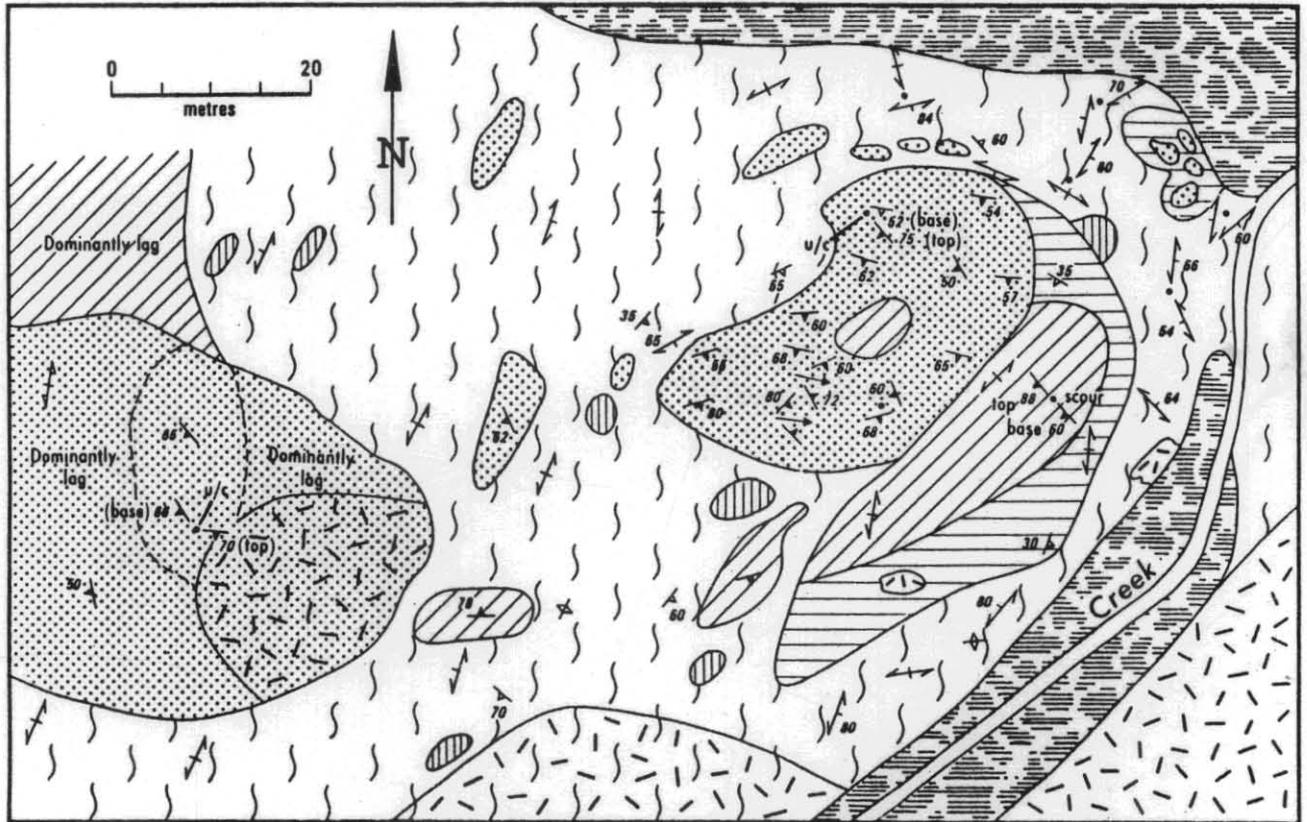
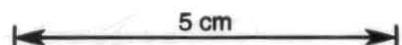


Figure 45. Detailed geological map of part of the Serpentine Hill Ultramafic-Mafic Complex.



### Olivine-rich sequence

The olivine-rich sequence is dominated by chrome spinel-rich olivine cumulates with zones which contain either orthopyroxene or feldspar as a post cumulus phase. The magma from which the olivine-rich sequence formed appears to have intruded the earlier layered orthopyroxene-rich sequence as sills, thus breaking this earlier sequence into irregularly shaped rafts, blocks and xenoliths. Layers of olivine with chrome spinel, and at times with post cumulus feldspar or orthopyroxene, formed within these sills. Where the sills were only a few metres thick the resultant layering was plastically deformed by sinking rafts and blocks of the layered orthopyroxene-rich sequence, forming zones in which the olivine-rich crystal mush has been squeezed between the accumulating blocks. Layering in undisturbed parts of this sequence is thin (less than 5 mm to 50 mm), at times discontinuous and lensoidal over a few metres.

Isolated blocks of the orthopyroxene-rich sequence have smooth scalloped edges where enclosed by the olivine-rich material, probably representing a reaction zone between the intruding and the earlier formed sequence. The only sharp irregular margins observed between the two sequences are in the disruption zones.

In some parts of the olivine-rich sequences occur 50 - 100 mm thick layers with cumulus orthopyroxene, 10 - 15 mm in length. These grains define a mineral foliation parallel to layering.

The olivine-rich sequence contains zones with a high chrome spinel content, either as a high concentration of disseminated grains or as irregular pods and lenses. In the area to the east of the road (fig. 44), a five metre thick zone in this sequence contains irregular pods and lenses (50 - 70 mm thick) of chrome spinel grains. The pods occur a few metres apart from each other along the zone. The enclosing rock type varies from an olivine cumulate with post-cumulus feldspar, to olivine cumulate with poikilitic orthopyroxene. This area does not contain blocks of the orthopyroxene-rich sequence but it is cut by late stage, thin, orthopyroxenite dykes which intrude the area at a high angle to layering within the olivine-rich sequence. Similar thin orthopyroxene dykes also cut both the ultramafic sequences in other parts of the complex. Within the area of the five metre thick zone of chrome spinel pods, numerous gabbro dykes intrude the sequence in a consistent direction, nearly parallel to layering.

Although samples of dunite now consist of serpentine group minerals, magnetite and spinel, the majority of samples still show a remnant

cumulate texture in thin section, as the olivine grain boundaries are outlined by dusty magnetite. Abundant euhedral chrome spinel grains are enclosed by the olivine grains and vary in size between 0.5 mm and 2 mm. Some spinel grains enclose 0.05 - 0.15 mm silicate grains. In samples with post-cumulus feldspar, the olivine grains vary in size from one to five millimetres, spinel grains are 0.25 - 0.35 mm and the feldspar is now hydrogarnet. Orthopyroxene grains, which form a mineral foliation in some olivine cumulate layers, are usually

between 8 mm and 10 mm in length.

Pods and lenses of chrome spinel concentrations consist of euhedral to subhedral grains, ranging in size from 0.1 - 1.0 mm, with a mosaic texture. Some of the grains originally enclosed early silicate grains, which are now altered to amphibole-group minerals. In samples with lower concentrations, the spinel grains occur as strings around cumulus olivine grains and are enclosed by post-cumulus orthopyroxene, or are between 0.7 - 1.15 mm euhedral to subhedral grains and cluster around stubby orthopyroxene grains in dominantly olivine cumulate layers. Due to the degree of serpentinisation, the only residual primary mineral phase is chrome spinel.

#### Two-Pyroxene Gabbro

In the area covered by Figure 45, gabbro intrudes both the orthopyroxene and olivine-rich sequences as irregular dykes, stringers and pegmatitic patches. In the area of gabbroic rocks to the south of the area covered by Figure 45 (fig. 44) evidence of the multiply intrusive nature of the gabbroic phase is found in the form of sharp contacts between areas of varying grain size. Irregularly cross-cutting the gabbroic and ultramafic sequences are late stage, thin and uniform diopside-plagioclase dykes (2 - 5 mm thick) and irregular pegmatitic patches, from which clinopyroxene crystals up to 100 mm in length have been recorded.

In thin section, the gabbro samples have a range in texture from fine-grained granular mosaic through medium-grained and coarse-grained granular to pegmatitic. The coarse-grained samples contain 3 mm to 4 mm stubby plagioclase grains in a matrix of anhedral clinopyroxene. The mineral chemistry of the gabbro is given in Table 5.

Rubenach (1974) considered that the layered ultramafic succession graded into a transition zone of ultramafic material and hypersthene gabbro. His transition zone, mapped as Csg on Figure 1 [around CP682673], is here considered to have been formed by the two-pyroxene gabbro intruding the olivine-rich sequence, which now forms this area, as sills are parallel to subparallel to layering. The strike difference between the sills and layering in the ultramafic sequence in the area around CP683674 is from 10 to 15 degrees.

#### Dundas Ultramafic Complex.

The Dundas Ultramafic Complex is now mainly massive serpentinite, with a small residual block of LPD succession at the north-western end [around CP680647]. The complex is exposed through a fault window within Dundas Group successions, which were originally deposited on top of the ultramafic body. The ultramafic detritus found within the Red Lead Conglomerate in the Razorback mine workings is considered to have come from this body and not from the younger Serpentine Hill Complex. The Serpentine Hill Complex is considered to have formed as a crustal chamber associated with the

low-titanium tholeiitic lavas which interdigitate with the Red Lead Conglomerate in the Ring River area.

The remnant area, in the north-west corner of this complex, contains partially serpentinitised ultramafic rocks with recognisable layering similar in dimension and rock type to that described from the Riley Knob area. Layers of serpentinite after dunite are between 10 mm and 50 mm thick, with olivine pyroxenite layers 10 - 20 mm thick. Orthopyroxenite layers are generally relatively fresh and occur as layers between 10 mm and 50 mm thick with an occasional layer between 150 mm and 200 mm. Disseminated chrome spinel is euhedral and ubiquitous on the weathered surface.

In thin section some samples of the pyroxenite layers have an even-grain granular texture, the orthopyroxene grains being between 0.25 mm and 2.75 mm with minor clinopyroxene grains between 0.1 mm and 0.15 mm. The clinopyroxene grains occur in areas between numerous orthopyroxene grains and were most probably post-cumulus phase. Chrome spinel grains in these samples are between 0.2 mm and 0.25 mm across. The majority of pyroxenite samples collected are highly deformed and consist of large (4 - 7 mm) anhedral orthopyroxene grains with thin clinopyroxene exsolution lamellae and kink bands, surrounded by a recrystallised mosaic of 0.1 - 0.5 mm orthopyroxene and minor clinopyroxene grains. Although the pyroxenite samples have a high degree of internal deformation, the layering is still easily recognisable.

Primary grains in olivine orthopyroxene samples have two grain size ranges. One has orthopyroxene between 1.25 mm and 2.25 mm and olivine grains between 0.75 mm and 1.75 mm. In the second range, the orthopyroxene grains are between 0.65 mm and 1.75 mm, the olivine being 1.35 - 2.75 mm and minor chrome spinel between 0.2 mm and 0.45 mm across. Numerous zones of brecciation through these samples now contain recrystallised mosaics of 0.1 - 0.25 mm grains.

Serpentinite after dunite layers has fine-grained magnetite outlining the original olivine grains which were 0.4 - 0.5 mm across with 0.2 - 0.35 mm chrome spinel grains.

The smaller body of sheared serpentinite to the south of the main body [around CP700615] contains a higher degree of deformation than the main Dundas body. Along the northern side of this body the serpentinite is massive, bottle green, and contains a high concentration of disseminated chrome spinel. Stichtite is common within the serpentinite area and individual areas of purple have a chrome spinel grain as a nucleus.

Small blocks of fractured, serpentinitised and altered pyroxenite occur in the serpentine. In thin section, these areas consist of large (10 - 30 mm), broken remnant orthopyroxene grains with clinopyroxene exsolution lamellae surrounded by zones of highly birefringent amphibole.

Earlier studies of this area are found in Taylor (1955) and Blissett (1962).

## Major and Trace Element Chemistry of Ultramafic Rocks.

### Introduction

Because of the high degree of serpentinisation of whole rock dunite samples in all successions, only representative samples were analysed. Pyroxenite and olivine pyroxenite samples from the LPD succession and pyroxenite samples from the LDH succession are relatively fresh, and samples from each of the main areas of LPD succession rocks were analysed. Whole rock analyses of ultramafic rocks from the Serpentine Hill Complex were not obtained due to the degree of serpentinisation. Analyses of gabbroic samples from this complex are discussed on Page 76.

Major and trace element analyses (Tables 14,15; Appendix 4) were made in an attempt to define any variation in the bulk rock chemistry within, or between, different areas of ultramafic rocks in the mapped area. Overall the results indicate that there are two chemically distinct groups. These correspond to samples from the LDH succession and samples from the LPD succession respectively, and the minor variations in each group exist in most areas of the respective successions.

When the analyses are plotted on a weight per cent AFM diagram (fig. 46) a small iron-enrichment trend is indicated by the samples from the LPD succession, being between  $M(=MgO) = 80.0$  and  $84.0$ . However in the Riley Knob area, variation in the AFM ratio of samples from along a 250 m strike section is similar to that obtained across the 120 m of section and both encompass the whole range defined by all samples. Each area consists of rafts of layered material surrounded by sheared serpentinite, and not a continuous physical section, and because of the results of the samples from the Riley Knob area, no overall reconstruction of a classical upward-iron succession can be made.

### Dunite Samples

Whole rock and trace element data are given for six partially serpentinised samples, four metadunite samples and five samples of serpentinite after dunite, three from the LDH succession and two from the LPD succession (table 14). The results are plotted on a weight per cent AFM diagram. Recalculated anhydrous compositions for the dunite reveal higher silica and lower magnesium values for the whole rock when compared with the composite olivine grains. This is most probably a result of both the small amount of low calcic, low alumina enstatite grains contained within these samples, and the non-isochemical serpentinisation which they have undergone.

The non-isochemical serpentinisation of the samples is reflected by the  $MgO/SiO_2$  ratio varying with the increase in the degree of serpentinisation, which is measured by an increase in loss on ignition value (fig. 47). The whole rock samples have an  $MgO/SiO_2$  average ratio of 1.12, compared with an average ratio of 1.24 for the olivine grains which constitute greater than 95 per cent of the

samples. Similarly the metadunite whole rock samples reflect the MgO loss during serpentinisation before contact metamorphism occurred, because even though the Mg value of the constituent olivine grains increase from an average forsterite content of 93.36 for unmetamorphosed samples to 94.84 in the metadunite samples, the MgO/SiO<sub>2</sub> ratio of the whole rock samples averages 1.17 in comparison to 1.28 for the constituent grains.

In metadunite samples, the higher forsterite content of the recrystallised olivine grains (table 19) is partly due to iron loss during serpentinisation and partly due to subsolidus re-equilibration at elevated temperatures over a period of time, possibly equivalent to the time taken for the metamorphosing granitic mass to cool. During serpentinisation, iron in excess of that which can be accommodated into the serpentine group minerals (usually lizardite) forms very fine-grained (dusty) magnetite. On metamorphism (>500°C, probably 600 - 700°C), the magnetite is not reincorporated into the recrystallised olivine lattice but stays as specific dusty grains scattered throughout the recrystallised olivine.

The second mechanism by which the forsterite content of olivine can be increased slightly is by subsolidus re-equilibration between olivine and coexisting chrome spinel at elevated temperatures over a period of time. Experimental work (Roeder et al., 1979) has indicated that the Mg<sup>#</sup> of spinel grains increases instead of decreasing with temperatures above 1200°C over very short time periods (two weeks). Field evidence from areas of high-magnesian andesite lavas near granitic masses indicates that the Mg<sup>#</sup> of the enclosed spinel grains decreases as the granitic body is approached (p.102). This change must be time related as well as temperature dependent. Evidence from coexisting olivine and chrome spinel grains within the metadunite zones of the LDH succession (table 20) also indicates a lowering of the Mg<sup>#</sup> of the spinel and an increase of the forsterite value of the olivine in comparison to the values obtained from samples in the surrounding unmetamorphosed areas (average spinel Mg<sup>#</sup> of 37 in the metadunite compared with an average of 49 in the surrounding dunite), again indicating the reverse to the experimental work.

Serpentinite samples after dunite from the LDH succession have an MgO/SiO<sub>2</sub> ratio of 1.06 and those from the LPD succession a ratio of 0.92, again indicating the non-isochemical nature of the serpentinisation process for dunite samples, and reflecting the overall lower magnesian content of the LPD succession.

On the AFM diagram (fig. 46) the dunite and associated orthopyroxenite samples from the LDH succession fall into a distinctive field between M = 87.0 and 88.5. The metadunite samples from this succession have a similar average M ratio (88.13), as do serpentinite samples (M av. = 87.45).

Dunite samples from the LPD succession at Colebrook Hill (analyses 14 - 15, table 14) have an average M value of 82.93, which falls within the field defined by the pyroxenite and olivine pyroxenite samples for this sequence (M = 80.0 to 84.5).

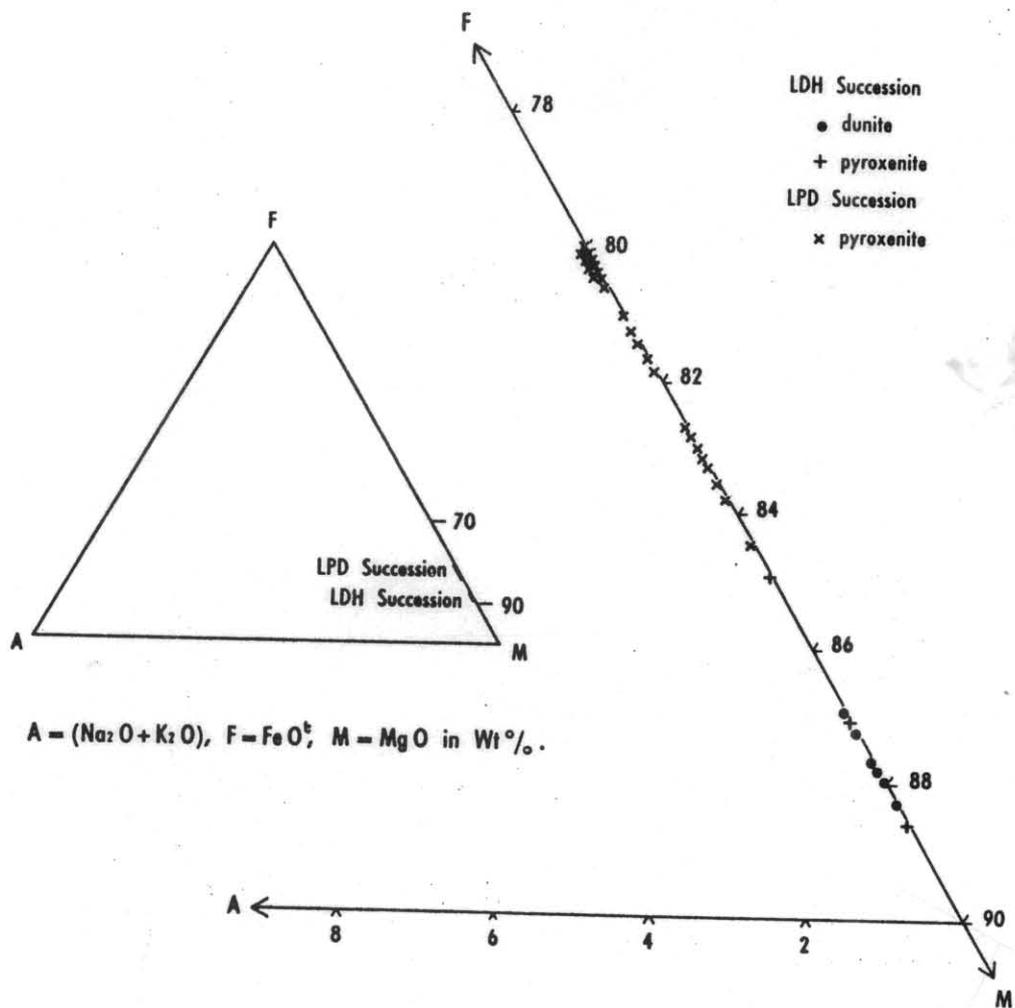


Figure 46. A.F.M. diagram with plot of analyses of ultramafic rocks from the LDH and LPD successions.

5 cm

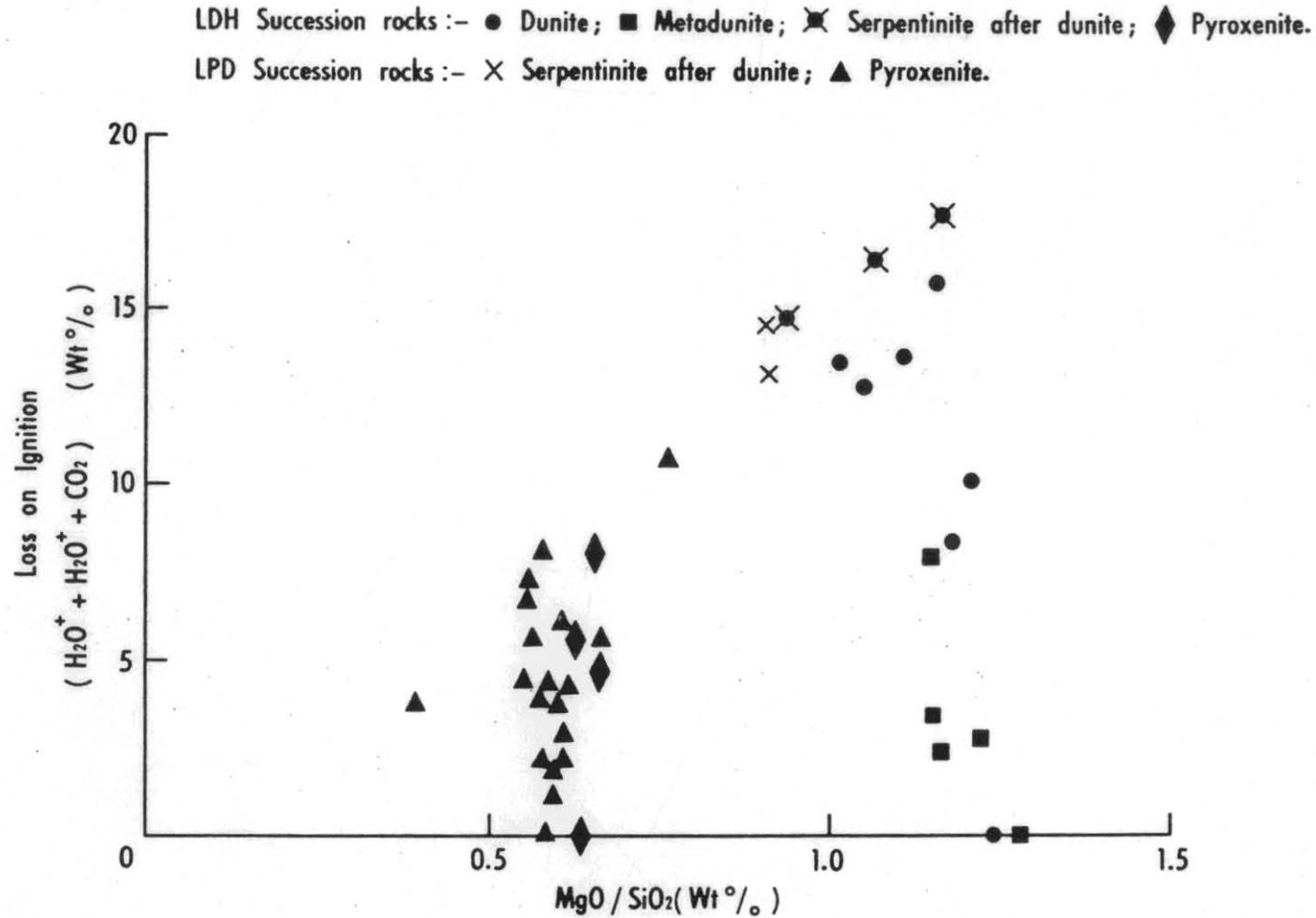


Fig.47 Loss on Ignition ~ MgO / SiO<sub>2</sub> ( Wt % ). Degree of isochemical serpentinisation.  
 Samples on base line represent parental compositions based on mineral chemistry.

5 cm

The chromium content of dunite samples ranges between 1750 ppm and 2200 ppm with an average of 1950 ppm. One sample (analysis 3, table 14) with an anomalously high chromium value (6860 ppm) was not used in the average. Nickel contents range between 2250 and 2700 ppm, with an average of 2486 ppm, but the mineral chemistry of these samples shows that nickel is not evenly distributed throughout the samples or grains. Electron probe analyses (table 16) of constituent grains only occasionally record nickel contents higher than detection limit (0.1889 wt% NiO, equivalent to 1485 ppm; the average whole rock value of 2486 ppm represents a NiO content of 0.3163 wt% if uniformly distributed).

### Pyroxenite Samples

The majority of pyroxenite samples analysed were orthopyroxenite (table 15) with subsidiary olivine and/or minor chrome diopside content. One sample of websterite was also analysed (analysis 19, table 15). The main difference between pyroxenite samples from within the LDH and LPD successions is that those from the LDH succession have lower Al<sub>2</sub>O<sub>3</sub> (average 0.28 wt% cf. 1.55 wt%), CaO (average 1.24 wt% cf. 2.03 wt%), and total iron contents (average 5.1 wt% cf. 7.15 wt%); and higher MgO contents (average 34.01 wt% cf. 30.80 wt%) for samples with less than 4.0 wt% CaO.

Chromium contents of the samples from both successions overlap and have a range of 2600 to 5800 ppm (average 4530 ppm). Nickel contents of samples from the LDH succession have slightly higher but overlapping values to those of the LPD succession, being 770 to 900 ppm (average 840 ppm) cf. 400 ppm to 859 ppm (average 586 ppm). When considering the total range of chemistry, the variations are most probably due to a different parental magma composition for the two successions.

Overall, the chromium content of pyroxenite samples is double that of the dunite samples, even though the dunite contains a higher percentage of chrome spinel grains. This makes chromium a useful element in identifying the original rock type of serpentinite samples when other evidence is lacking. The high chromium content of pyroxenite samples also reflects the ability of chromium to enter the pyroxene mineral lattice in comparison to olivine, when the composition and the pressure and temperature conditions of crystallisation are similar.

The average MgO/SiO<sub>2</sub> ratios between component minerals and bulk rock from the same pyroxenite samples from the LPD succession indicate that serpentinisation of the majority of pyroxenite samples was an isochemical process, as both the constituent minerals and whole rock have MgO/SiO<sub>2</sub> ratios of 0.59, although one sample (analysis 17, table 15) has obviously gained MgO.

In pyroxenite samples from the LDH succession the average MgO/SiO<sub>2</sub> ratio for the whole rock and the mineral components is 0.65 and 0.63 respectively, indicating a slight enrichment in MgO during serpentinisation, probably at the expense of the associated dunite layers.

When the samples from the area studied are compared on a weight per cent AFM diagram with ultramafic rocks from other areas, the LPD succession samples are always more magnesian than rocks from the large layered complexes (e.g. Bushveld and Stillwater Complexes, which have M values of less than 0.79). However, they are similar to the most magnesian samples found in 'alpine' and 'ophiolitic' complexes in New Zealand (Coleman, 1966), Newfoundland (Church, 1977), Vourinos (Jackson, Green and Moores, 1975; Harkins, Moores and Green, 1980); Troodos (Moores and Vine, 1971) etc. This indicates that the Tasmanian samples probably originated from a more magnesian magma than these other complexes. The other main feature of the Tasmanian complexes is that they are orthopyroxene-rich and not clinopyroxene-rich.

#### Mineral Chemistry.

Samples from each of the three different ultramafic successions were analysed by electron micro-probe to obtain the component mineral characteristics. Similar data was collected from samples from other areas of ultramafic rocks for the purpose of correlation of the different areas, and to obtain the range of mineral chemistry exhibited by the different complexes.

The mineral grains in most samples were tested by a five-point traverse for chemical zoning and then five to eleven grains of each remnant mineral species were analysed from each sample. The analyses were then averaged to obtain a representative analysis for each mineral species in each sample. Overall, no mineral grain showed significant or consistent zoning. Nickel was randomly distributed throughout olivine grains, as was calcium and aluminium in orthopyroxene grains from the LDH succession. Studies on exsolution in pyroxene grains in samples from the LPD succession were not undertaken and the grains analysed from samples of this succession were as homogeneous as could be obtained. Due to serpentinisation, chrome spinel grains usually had a thin magnetite rim but inside this rim the grains were fairly homogeneous. Tables of the average mineral compositions are included as Appendix 4.

#### Layered Dunite-Harzburgite Succession.

##### Harman River area

Analyses of coexisting mineral phases of fourteen samples of serpentinised dunite and two of orthopyroxenite were obtained from samples collected from across a 1500 m section between CP608867 and CP628863 of the LDH succession in the Harman River area of the Wilson River Ultramafic Complex. Seven samples of serpentinised dunite from

the Mt Stewart area and three from the Adamsfield area were also analysed so that the correlation of the LDH succession on field and petrographic evidence could be tested by mineral chemistry. Eight metadunite samples were probed to obtain the characteristics of this group of rocks.

Olivine grains from within serpentinitised dunite samples have a very uniform composition of Fo93-94 (average 93.36, table 16) across the 1500 m section. The olivine grains from this succession consist only of SiO<sub>2</sub>, MgO and FeO, with some samples also registering a nickel content (0.35 wt%). If NiO was detected in a specific grain, the majority of analyses of that grain and the majority of grains from the sample recorded nickel in the analysis. When a diffuse beam analysis of a grain which registered nickel on a spot analysis was obtained, nickel would not be measured above detection level.

Orthopyroxene grains within the dunite samples always had a calcium content of less than 0.5 wt%, with the majority of grains having contents below detection limit. The orthopyroxene grains from this area have a compositional range of (Ca:Mg:Fe = 0.0 - 0.5:93.3 - 93.7: 6.5 - 9.1) (table 17). The lenses and veins of coarse-grained orthopyroxenite, which are considered on field evidence to be late stage, have a similar range of chemistry. The compositional variation between orthopyroxene grains in pyroxene-bearing dunite from the western (basal?) side of the complex in this area (En93.5 - 93.7), and those from coarse-grained orthopyroxenite lenses one kilometre up section (En93.3 - 93.5) is so small that it is insignificant and implies a very uniform parental composition and pressure and temperature regime during formation. Chemical evidence for the coarse-grained pyroxenite lenses and dykes being later than the layered dunite-harzburgite in which they occur is shown by composition of the minor olivine component of these rocks. In two areas of LDH succession, at Mt Stewart and Adamsfield, the olivines from the coarse-grained orthopyroxenite lenses are Fo86.4 and Fo89 respectively. This is in comparison to Fo93 - 94 and Fo93 respectively for olivine from within the layered sequence in which the orthopyroxenite samples occurred.

Within orthopyroxene grains from this succession, and correlates in the Mt Stewart and Adamsfield areas, whenever Al<sub>2</sub>O<sub>3</sub>, CaO, or Cr<sub>2</sub>O<sub>3</sub> are recorded above detection limit the values are less than 0.5 wt%, 0.5 wt% and 0.3 wt% respectively. These three elements are unevenly distributed within grains, and not all spot analyses on a specific grain registered the presence of the element, and not all grains within a sample registered amounts of the elements above detection limit. The orthopyroxene grains in the LDH succession have a composition similar to that predicted for protoenstatite.

As with olivine and orthopyroxene, chrome spinel grains in samples of the LDH succession (table 18) have a very small range of composition and are usually composed of Al<sub>2</sub>O<sub>3</sub>, Cr<sub>2</sub>O<sub>3</sub>, FeO and MgO. An occasional grain registered MnO or TiO in its composition, with Mn being more frequently present. When present, Mn is always less than 0.5 wt% and Ti less than 0.25 wt%. Only rarely does Mn occur in more than half of the analyses taken in any one sample.

Overall, dunite from the LDH succession has olivine grains of Fo93 - 94, orthopyroxene grains of En93 - 94 and chrome spinel with a 100 x Cr/(Cr + Al) ratio (Cr\*) of 87 - 93 with a variable 100 x Mg/(Mg + Fe2+) ratio (Mg\*) but an average of 49 (fig. 48). Orthopyroxene crystals in the associated coarse-grained pyroxenite lenses and dykes are En93 - 94 with the associated chrome spinel grains having a Cr\* of 92 - 94, and Mg\* of 47 (average).

Mt Stewart and Adamsfield areas

Olivine from serpentinised dunite in the Mt Stewart area has a compositional range of Fo92 - 93. The associated chrome spinel grains have Cr\* of 89 - 94. The Mg\* is lower than in the Harman River area, being equal to an average of 41.90. This lower Mg\* is considered to result from metamorphism by the underlying granitic mass, as chrome spinel from serpentinite or high-magnesian andesite and associated basaltic pyroxenite samples in close proximity to granitic masses always has lower Mg\* than in similar samples at a distance from the granitic rocks.

Coarse-grained orthopyroxenite, associated with the dunite, has orthopyroxene grains with En92 and chrome spinel of Cr\* of 89 with the Mg\* being 36. Enclosed olivine grains are Fo86. Considering that the samples from this area are fifteen kilometres away from the Harman River body, the analyses of this succession are extremely uniform. Although re-equilibration of the succession is a possible method of obtaining such consistent mineral chemistry over a large area, it will be seen (p.147) that the mineral chemistry of this succession is consistent with having been a primary precipitate from the spatially associated high-magnesian andesite.

Correlates of the LDH succession at Adamsfield contain olivine of Fo92 - 93 and orthopyroxene of En93 - 94. Neither calcium nor aluminium were detected in quantities above detection limit. Chrome spinel has a Cr\* of 90 - 94 and a range of Mg\*, the average of which is 48. Further mineral chemistry analyses of samples other than those used in this study, from this area, can be found in Varne and Brown (1978).

An extra unit exists in the LDH succession in the Adamsfield area which has so far not been found in other areas of the succession. This unit is a massive coarse-grained orthopyroxenite (Brown, 1972; Varne and Brown, 1978). Samples from this unit contain orthopyroxene of En89, olivine of Fo89 and chrome spinel having a Cr\* of 90. This massive orthopyroxenite is considered to be a correlate of the late-stage orthopyroxenite veins and dykes of the Harman River and Mt Stewart areas. Field relationships in the Adamsfield area indicate that the orthopyroxenite overlies the interlayered dunite-pyroxene dunite-harzburgite sequence. The present outcrop relationship is an irregular boundary with evidence of interdigitation, possibly due to later plastic and/or solid flow.

Overall, the LDH succession is a highly depleted succession of well-layered dunite, pyroxene-bearing dunite, harzburgite, and

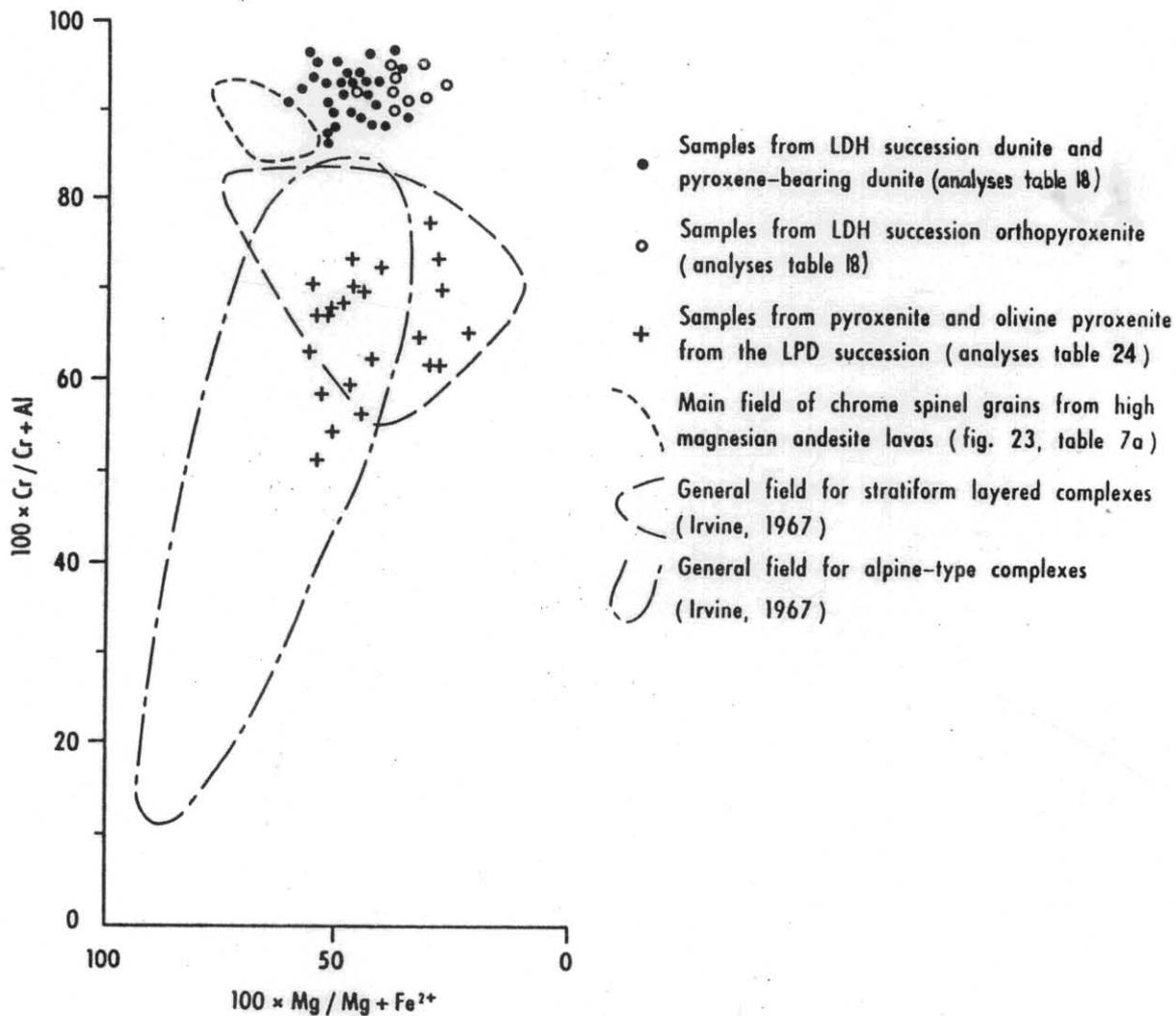


Figure 48.  $(Cr \times 100)/(Cr + Al) \sim (Mg \times 100)/(Mg + Fe^{2+})$  diagram for chrome spinel samples from the LDH and LPD successions.

massive orthopyroxenite which has a characteristic high magnesian, high chrome chemical signature allowing correlates of this succession to be unambiguously identified. The chemical composition of the orthopyroxene is consistent with the grains originally having been protoenstatite. There is no evidence of exsolution lamellae of a calcic pyroxene nature in any grain studied from within samples of this succession. The overall chemical data suggests that this succession is likely to have formed from a liquid in the forsterite + protoenstatite + chrome spinel + liquid field.

#### Layered Pyroxenite-Dunite Succession.

##### Riley Knob area

Only partially serpentinitised olivine pyroxenite and pyroxenite layers were able to be analysed from the LPD succession as no sample of serpentinitised dunite contained remnant olivine cores. The orthopyroxene minerals range between En85 and En89 and have an average composition of (Ca:Mg:Fe = 1.87:87.82:10.33), with the calcium content varying between 0.6 wt% < CaO < 2.0 wt% and the aluminium content between 0.75 wt% < Al<sub>2</sub>O<sub>3</sub> < 2.0 wt% (table 22, Appendix 4). Olivine grains vary between Fo87 and Fo90 (table 21), and usually have a similar Mg# to the coexisting orthopyroxene mineral. Minor chrome diopside grains (table 23) average (Ca:Mg:Fe = 47.26:48.94:3.78) and chrome spinel has a Cr# of 63.86 with a Mg# of 48.93. The range of Cr# in spinel grains (table 24) from the succession is far larger than that from the LDH succession, and grains from the two successions define totally separate fields on a Cr# - Mg# diagram (fig. 48).

The range in chemistry of coexisting mineral phases in samples from this area indicates a well-defined hiatus between the chemistry of the coexisting phases from within the LPD and LDH successions. This hiatus is reflected by the higher FeO, Al<sub>2</sub>O<sub>3</sub> and CaO contents of the orthopyroxene grains, higher FeO of the olivine grains, and significantly lower Cr<sub>2</sub>O<sub>3</sub> and higher Al<sub>2</sub>O<sub>3</sub> contents of the chrome spinel grains. The presence of chrome diopside as a coexisting mineral phase also indicates a bulk compositional difference between the magmas from which the two successions formed.

A similar range of chemistry in the coexisting mineral phases is found in samples from all other areas of LPD succession (tables 21 - 24), giving an average olivine composition of Fo87.48; orthopyroxene composition of (Ca:Mg:Fe = 1.94:86.41:11.65); clinopyroxene of (Ca:Mg:Fe = 46.86:48.66:4.49) and chrome spinel with Cr# of 65.49 and Mg# of 42.97, indicating a consistent parental magma composition for the now spatially separated areas of this succession. As with the LDH succession correlates at Adamsfield, the LPD succession samples from this area have compositions corresponding very closely to the overall average values of the whole LPD succession (tables 21 - 24).

When chemical composition variation diagrams (fig. 49) are plotted for orthopyroxene analyses from all samples from both the LDH and LPD successions, CaO, Al<sub>2</sub>O<sub>3</sub>, MgO and FeO all have good, scattered, linear

relationships with each other, indicating a compositional control on crystallisation as well as temperature, pressure and oxygen fugacity control.

The compositions of coexisting orthopyroxene and clinopyroxene grains from samples of the LPD succession (fig. 50), irrespective of which area the samples came from, have an overlapping compositional field with parallel tie lines and a restricted range in chemistry but with a small iron-enrichment trend, again suggesting a dominant bulk chemical control. The coexisting pyroxene species in the LPD succession lie at the magnesian end of any compositional trend defined by coexisting pyroxene from peridotite samples from both the large layered ultramafic complexes (Bushveld, Stillwater etc.) and 'alpine' or 'ophiolitic' complexes.

Although there is a small range in the composition of the coexisting pyroxenes and their tie lines are parallel, samples from different areas overlap the range defined by the samples from Riley Knob and there is not a discernible trend from which a theoretical body may be reassembled along the lines of an upward iron-enrichment trend.

When analyses of coexisting orthopyroxene and chrome spinel are plotted (fig. 51a), Al<sub>2</sub>O<sub>3</sub> defined a scattered linear relationship between coexisting pairs, again indicating a compositional control. In terms of weight percent content, the LDH succession samples are extremely depleted in Al<sub>2</sub>O<sub>3</sub> in comparison to samples from any other recorded ultramafic body, with the samples from the LPD succession defining a field at the lower end of the range defined by a spectrum of all existing ultramafic types (fig. 51b, 52).

When chrome spinel grain analyses from both successions are plotted on a  $100 \times Cr / (Cr + Al) \sim 100 \times Mg / (Mg + Fe^{2+})$  diagram (fig. 48; table 24), the grains from samples of LDH succession rocks define a field more enriched in chromium than any other ultramafic body yet reported. The spinel grains from the orthopyroxenite veins and lenses are slightly more iron rich than those in dunite and pyroxene-bearing dunite samples, again suggesting a later stage formation of the massive, coarse-grained orthopyroxene phase, as is indicated by both field and olivine composition data.

Analyses of the chrome spinel grains from the LPD succession have a larger compositional range than those from the LDH succession. They define a field which overlaps chrome spinel compositions from both alpine-type and large layered peridotite bodies (fig. 48) and again show the hiatus in chemistry between the LDH and LPD successions.

When plotted on a Cr-Fe<sup>3+</sup>-Al triangular plot (fig. 53), spinel grains from the LDH and LPD successions form two separate fields, both with a relatively small range in Fe<sup>3+</sup>, the majority of which have an exceedingly low Fe<sup>3+</sup> component. The samples do not define an Fe<sup>3+</sup> enrichment trend, indicating a fairly consistent and low oxygen fugacity environment of formation for both of the successions.

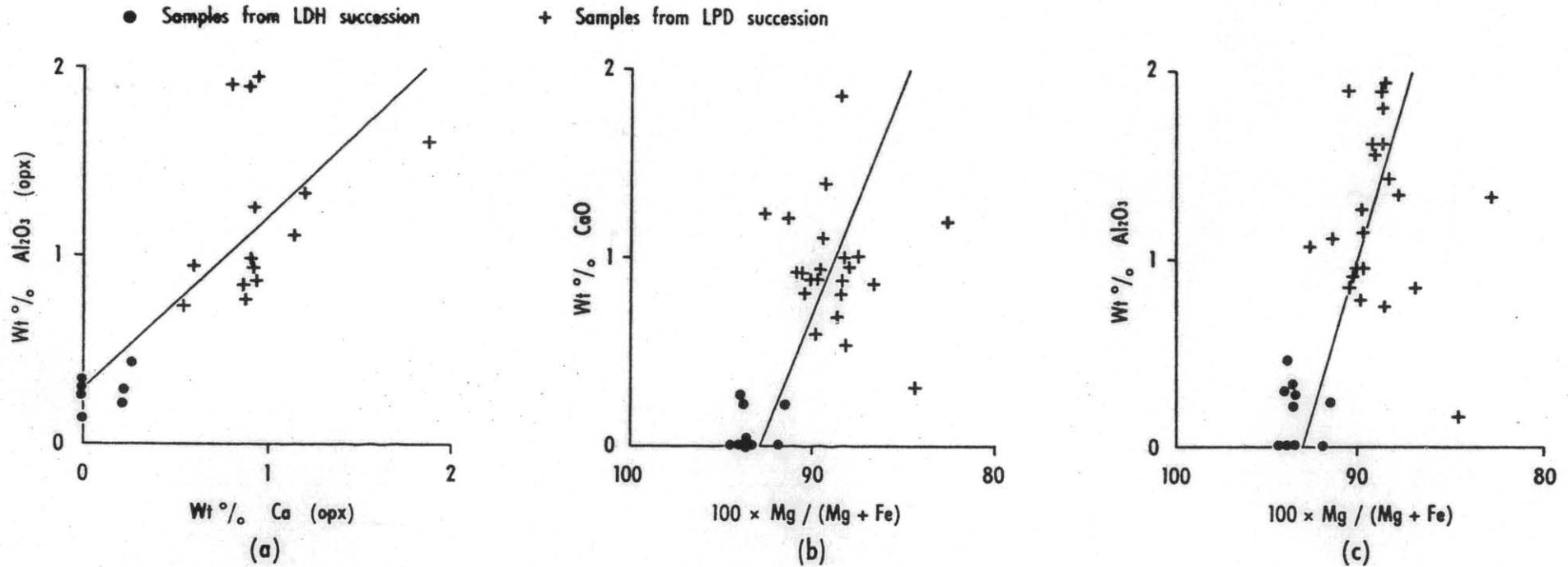
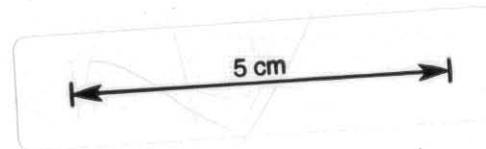


Fig. 49 Chemical variation diagrams for orthopyroxene — (a)  $\text{Al}_2\text{O}_3 \sim \text{CaO}$ , (b)  $\text{CaO} \sim \text{Mg}^*$ , (c)  $\text{Al}_2\text{O}_3 \sim \text{Mg}^*$ .  
From the LDH and LPD successions.



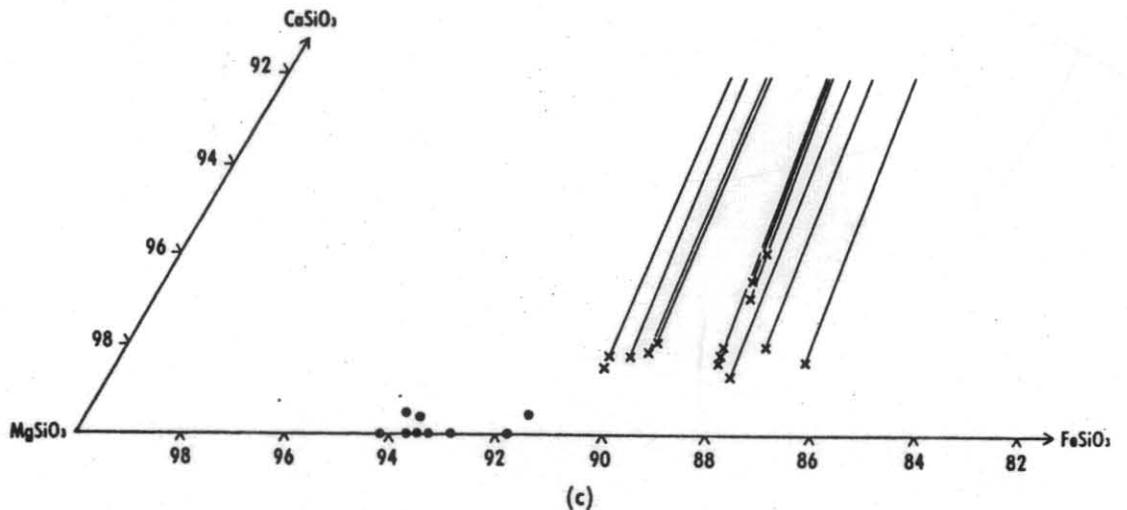
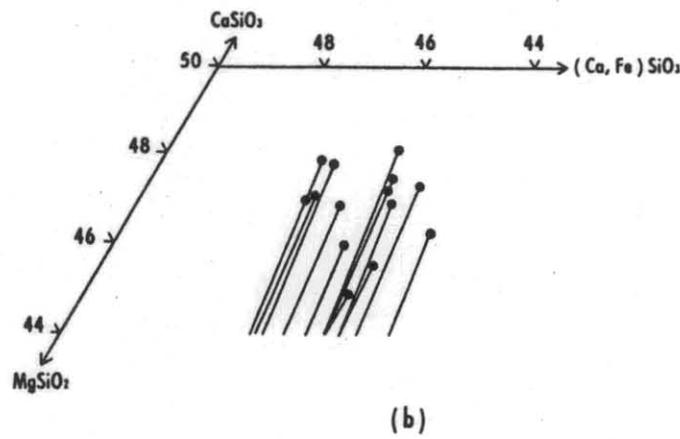
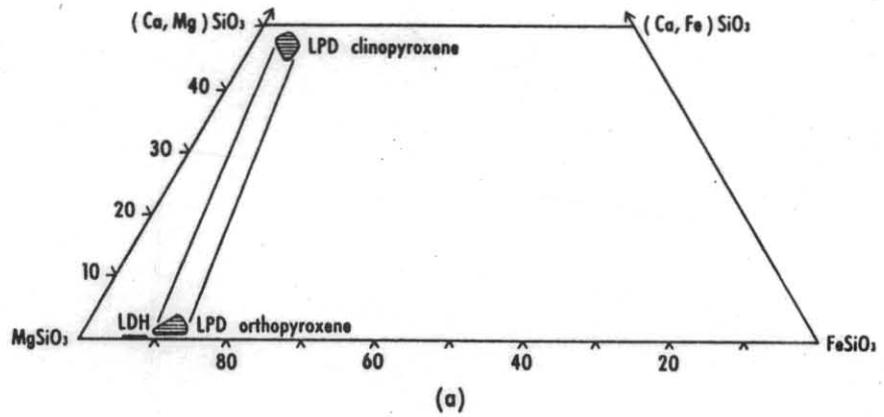


Fig. 50 (a) Part of the pyroxene quadrilateral, showing area of plot of orthopyroxene from the LDH succession (fig (c)), and orthopyroxene + coexisting clinopyroxene (hatched areas with boundary tie lines) from the LPD succession (figs (b), (c)).  
 (b) Part of the pyroxene quadrilateral, showing compositions and direction of tie lines for clinopyroxene from the LPD succession (compositions table 23)  
 (c) Part of the pyroxene quadrilateral, showing compositions and direction of tie lines for orthopyroxene from the LPD succession (crosses), and composition of orthopyroxene from the LDH succession (dots), (compositions tables 17 and 22).

5 cm

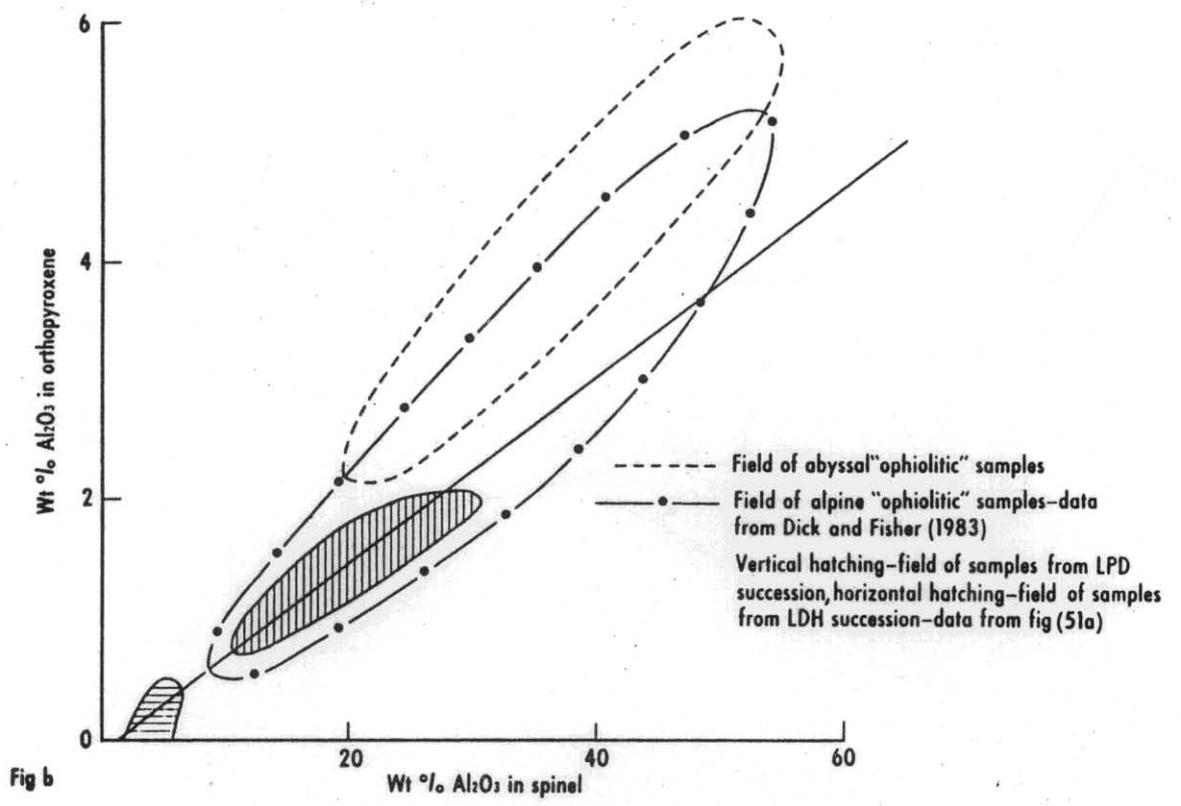
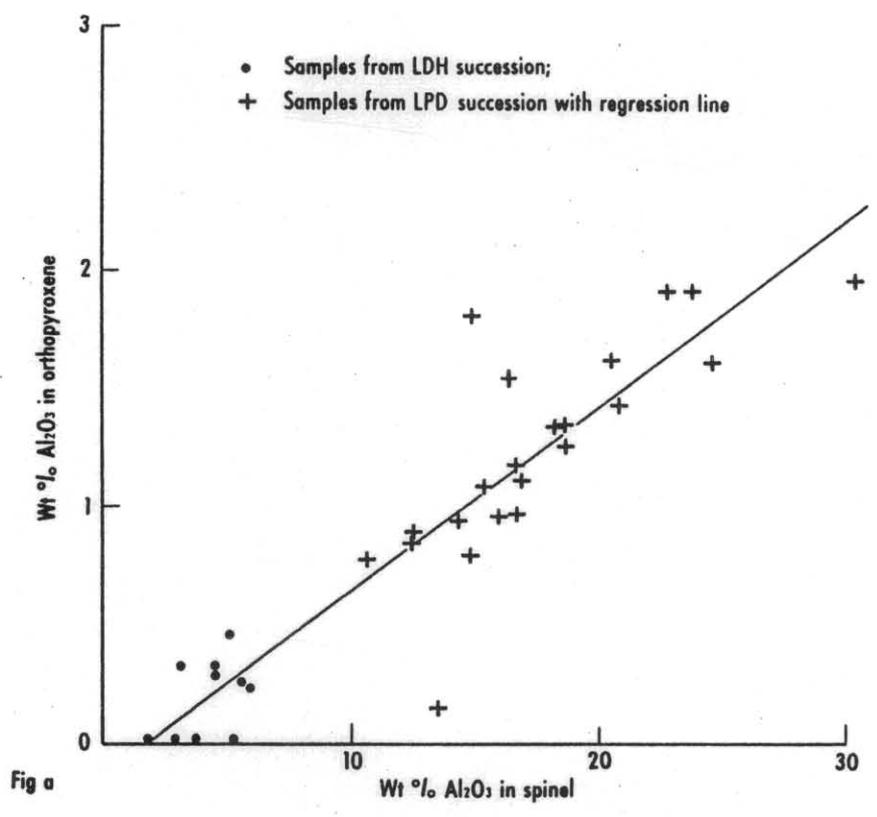


Figure 51. Variation in Al<sub>2</sub>O<sub>3</sub> in coexisting orthopyroxene and chrome spinel.

5 cm

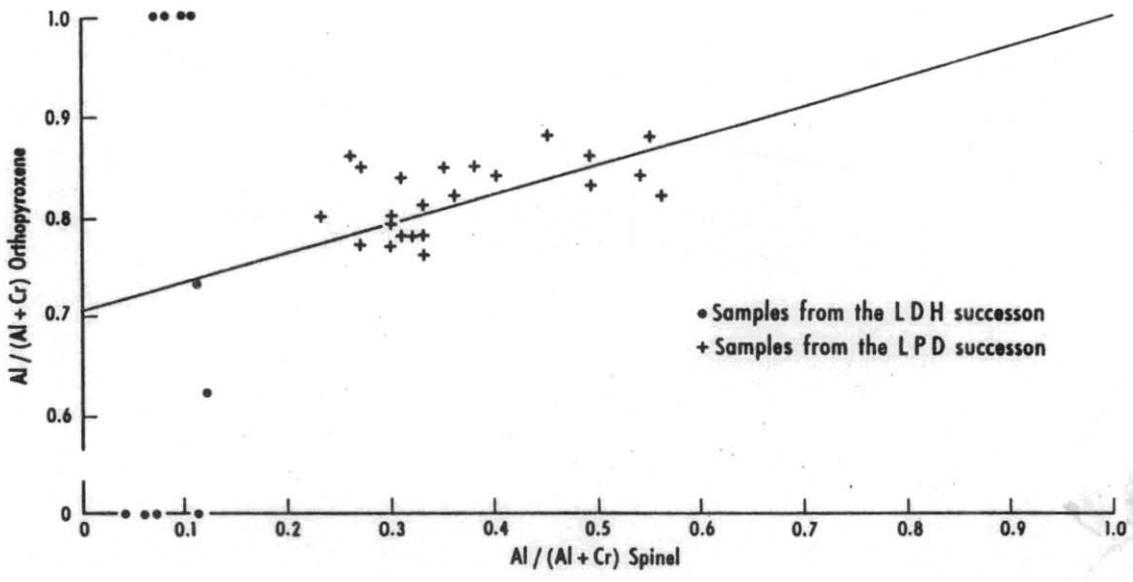


Fig. 52(a) : Distribution of Al and Cr in coexisting orthopyroxenite and spinel for samples from the LDH succession and LPD succession with regression line defined by all samples

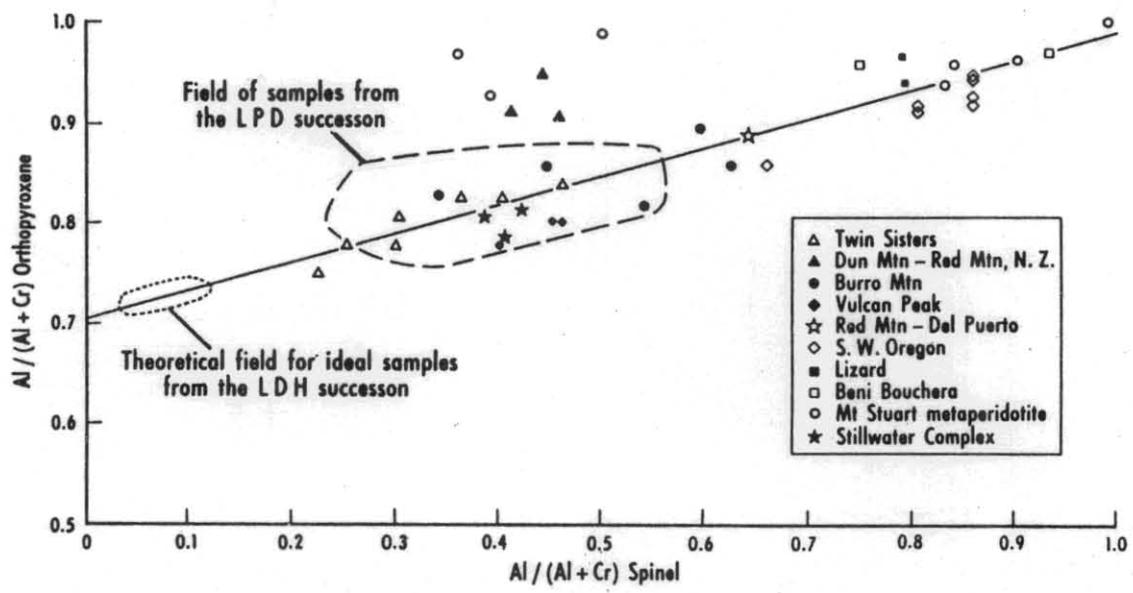
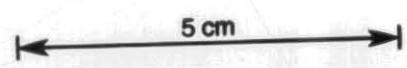


Fig. 52(b) : Distribution of Al and Cr in coexisting orthopyroxene and spinel from alpine-type peridotite. After Dick (1977) with regression line defined by samples from the Tasmanian ultramafic samples. Data for Tasmanian samples from fig. 52(a)



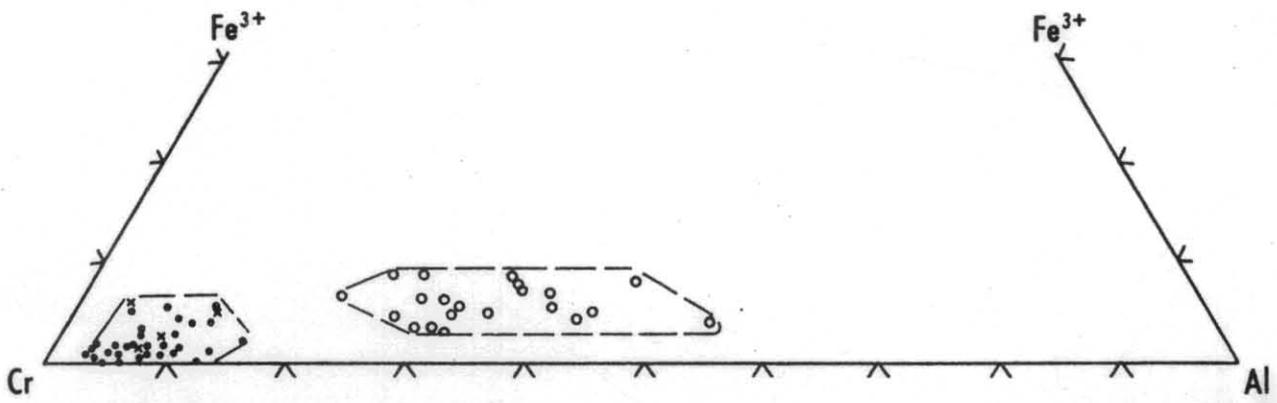


Figure 53a.  $Cr \sim Al \sim Fe^{3+}$  plot of chrome spinel samples from the LDH and LPD successions:

- dunite, pyroxene bearing dunite and harzburgite
- x massive orthopyroxenite
- o samples from LPD succession.

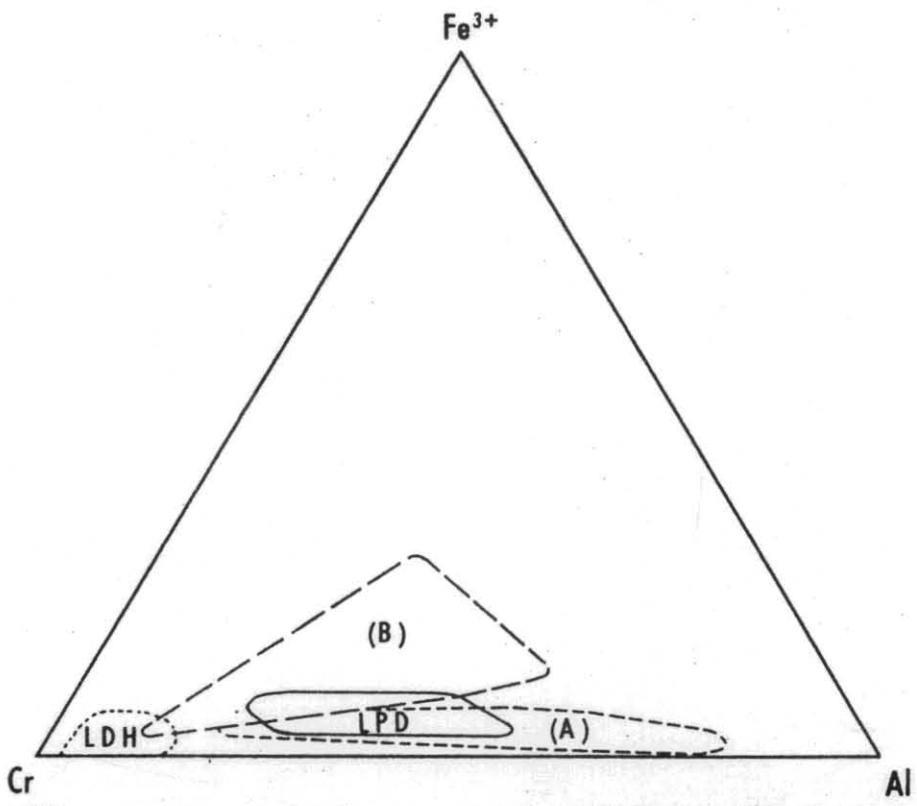
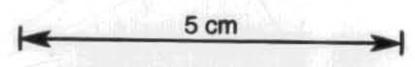


Figure 53b.  $Cr \sim Al \sim Fe^{3+}$  diagram with field of spinel compositions from the LDH and LPD successions (fig. 53a) compared with fields of spinel composition from a non- $Fe^{3+}$  increasing body (A) (Josephine Peridotite, Dick, 1977); and an  $Fe^{3+}$  increasing body; (B) (Marum Peridotite, Jaques, 1981).



## Layered Pyroxenite-Peridotite and associated Gabbro.

### Serpentine Hill area

The degree of serpentinitisation of the LPG succession frustrated an attempt to gain a full range of silicate mineral chemistry. Only pyroxenite samples within the orthopyroxene-rich sequence contained primary silicate minerals. Orthopyroxene grains from this sequence (table 25) have an average of (Ca:Mg:Fe = 2.1:87.0:10.9), with coexisting clinopyroxene being (Ca:Mg:Fe = 47.6:48.4:4.0). Associated chrome spinel grains (table 26) have an average Cr# of 62.05 and Mg# of 46.75 (fig. 54). Silicate grains enclosed by the spinel are now tremolite or tremolitic hornblende (table 25).

The only residual primary phase in the olivine-rich sequence is chrome spinel. Analyses of spinel grains from samples within the general olivine-rich sequence have a slightly lower average Cr# than those within samples from the orthopyroxene-rich sequence (59.15 compared to 62.05), whereas samples from the five metre thick zone of chrome spinel pods and lenses have a much higher average ratio of 68.85 (table 26). All spinel analyses from the LPG succession plot within the field defined by samples from the LPD succession (fig. 54), but the presence of plagioclase as a mineral phase, the evidence of multiple magma phases, the presence of associated gabbro and the very different Platinum Group Element contents (Brown et al., in prep), all suggest that the LPG succession is derived from a different parental magma to those which formed the LPD and LDH successions.

### Summary of Ultramafic Rock Successions

In the past, the ultramafic complexes of western Tasmania have been described as both disrupted ophiolites (Rubenach 1973, 1974) and 'ophiolitic' (Varne, 1978; Varne and Brown, 1978; Brown et al., 1980). With the evidence obtained in this study no ultramafic rock complex within Tasmania can be described as an ophiolite or 'ophiolitic', nor can the tectonic environment of formation of these bodies be suggested as having been part of an ocean-floor setting.

The ultramafic rocks of western Tasmania are orthopyroxene-rich and this feature alone separates the ultramafic rocks of this area from the world-wide dominantly clinopyroxene-rich sequences, which are usually associated, by the describing authors, with spreading ridge, ocean-floor, island-arc or back-arc environments.

The Layered Dunite-Harzburgite Succession is a well-layered sequence dominated by dunite and pyroxene-bearing dunite in comparison to the harzburgite content. Late stage massive coarse-grained orthopyroxenite units, and/or dykes and veins, overlie or cut the layered sequence. As well as distinct layering, this succession also contains primary mineral foliations, parallel to layering, of orthopyroxene and chrome spinel. The whole succession has an overprinted tectonic foliation which elongates and optically strains olivine grains, forms kink bands in orthopyroxene grains and pull

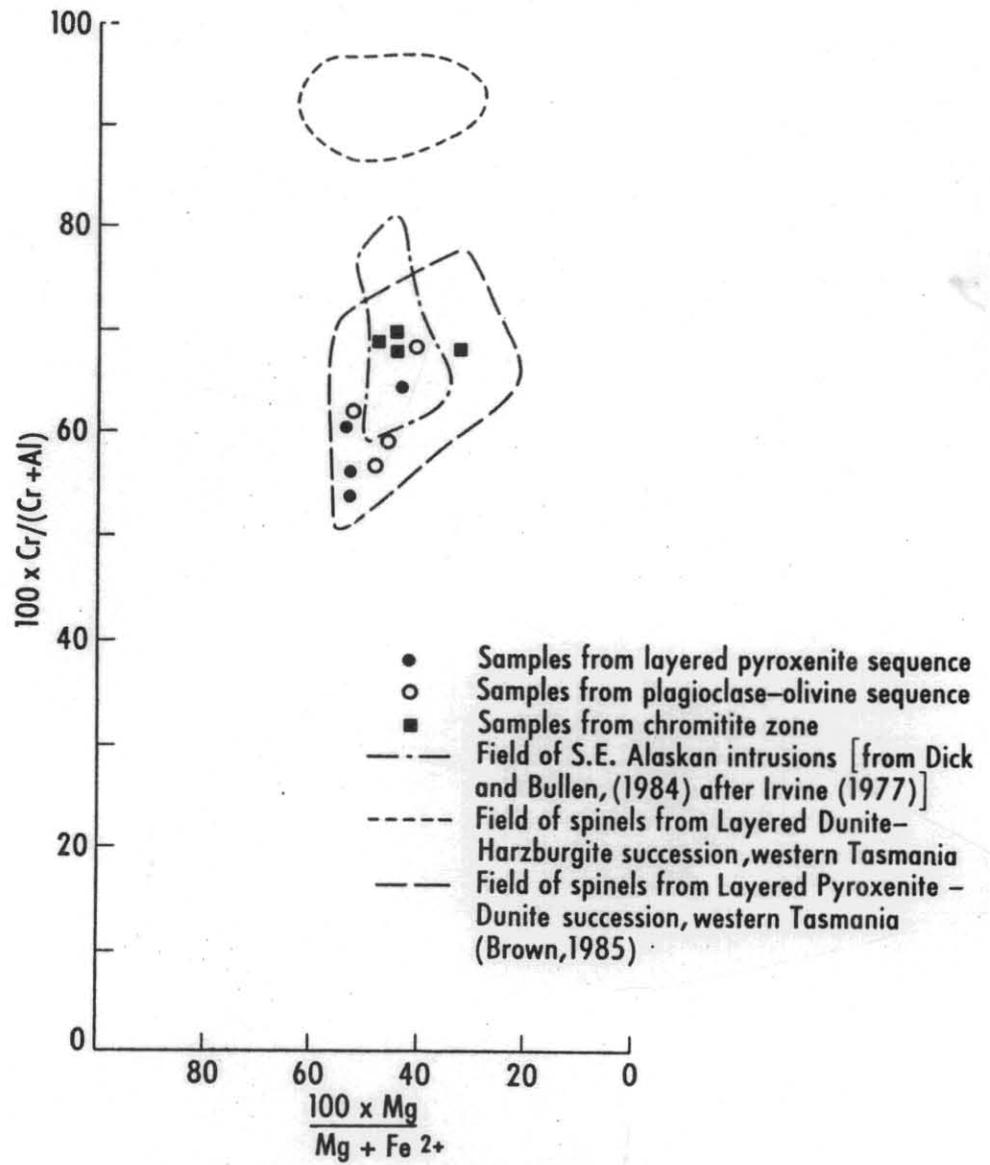
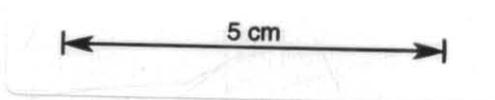


Figure 54.  $(Cr \times 100) / (Cr + Al) \sim (Mg \times 100) / (Mg + Fe^{2+})$  diagram with the analyses of chrome spinel samples from Serpentine Hill Ultramafic-Mafic Complex.



apart structures in large (2 mm) euhedral chrome spinel grains. No evidence consistent with protogranular or porphyroblastic textures has been observed but the interpretation of original textures is ambiguous due to the masking effect of serpentinisation. Chrome spinel grains are euhedral and a co-precipitating phase with olivine. No rounded or holly-leaf shaped spinel grains were observed, again indicating that only primary mineral phases are present.

The Layered Pyroxenite-Dunite Succession is again orthopyroxene-rich but also contains minor chromian diopside grains in most pyroxenite layers. This succession is also characterised by very thin to thin layering and unambiguous cumulate and adcumulate textures, being either granular or interlocking. There is a chemical hiatus between mineral constituents of the LDH and LPD successions, possibly suggesting two different source magmas. Samples from the LPD succession define a small iron-enrichment trend and plot at the magnesian end of any trend defined by other ultramafic bodies. The succession was dismembered in the solid state and rafts of layered material with serpentinitic sheaths were emplaced into basins of deposition before the middle Middle Cambrian.

The third subdivision of the ultramafic complexes of western Tasmania is a multi-phase ultramafic-mafic succession, consisting of layered pyroxenite-peridotite and associated gabbro (LPG succession). This succession consists of an original layered orthopyroxenite-rich sequence, with numerous sedimentary-style structures. An olivine-rich sequence intrudes and disrupts the first sequence, forming a layered succession incorporating blocks of the orthopyroxenite-rich sequence and containing zones which are rich in chrome spinel. Both of these ultramafic sequences were then intruded by a phase of massive two-pyroxene gabbro. Although the mineral chemistry of the constituent mineral phases of the orthopyroxene-rich sequence is similar to that of the LPD succession, it contains plagioclase as a major post-cumulus phase and layer types (e.g. deferred graded dunite) not found in the LPD succession. The olivine-rich sequence does not exist in the LPD succession and also contains plagioclase as a post-cumulus phase. Some of the gabbro samples appear to contain cumulus plagioclase. This third subdivision of the ultramafic rocks also contains a higher overall PGE content than either the LDH or LPD succession.

The obvious relationships between different chemical elements in different mineral phases of these successions indicate a compositional control. Low  $TiO_2$ ,  $Al_2O_3$ ,  $CaO$ ,  $Na_2O$  and  $K_2O$  contents of the coexisting mineral phases in the LDH succession probably indicate a low abundance of these elements in the parental magma for this succession. As spinel is the only mineral which takes large amounts of  $Fe^{3+}$  into its lattice, the amount of ferric iron within spinel grains is considered to be a measure of the  $Fe^{3+}$  in the melt, which is in turn a direct function of the prevailing oxygen fugacity. Thus both the LDH and LPD successions formed under conditions of low (LPD) to very low (LDH) oxygen fugacity.

The coexisting mineral chemistry of the LDH succession indicates formation under bulk chemical control in the forsterite(Ol) +

protoenstatite(Pen) + spinel(Sp) + liquid stability field under conditions of low oxygen fugacity, high temperature and low pressure, and regularly fluctuating between Ol + Sp; Ol + Pen + Sp and Pen + Sp, with the degree of incongruent melting of protoenstatite possibly dictating whether pyroxene-bearing dunite or harzburgite was formed.

Because of the sharp layer boundaries and thin to very thin layering in both the LDH and LPG successions, and the similar densities of olivine and enstatite, gravitational settling of the cumulus mineral phases could not have produced these successions.