GEOLOGICAL SURVEY OF CANADA

OPEN FILE 2067

GEOLOGY OF THE BIRD RIVER SILL AT THE CHROME PROPERTY, SOUTHEAST MANITOBA

B. Williamson

1990

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Inside Front Cover

Manitoba
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Contribution to Canada-Manitoba Mineral Development Agreement 1984-89, a subsidiary agreement under the Economic and Regional Development Agreement. Project funded by the Geological Survey of Canada.

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ABSTRACT

Mapping of the Bird River Sill at the Chrome property has resulted in the preparation of a 1:2000 scale geological map of the property, a 1:500 scale detailed map of part of the lower Ultramafic Series, and four 1:200 scale detailed map sheets of the Chromitiferous Zone. This entailed as well the establishment of a revised stratigraphic subdivision of the Sill.

The Sill has been subdivided into three series and each series into zones and subzones as applicable, based on mappable criteria. The lowermost Ultramafic Series contains variably textured peridotite with minor chromitite, chloritite, and gabbro. An overlying Transition Series contains two distinctive peridotites and gabbro. The uppermost Mafic Series contains a variety of gabbros, with subordinate amounts of diorite and trondhjemite.

Three magmatic cycles occur, evidenced by peridotite to gabbro transitions. Platinum Group Element enriched disseminated sulphides are present in the two lowermost cycles, and numerous chromitite layers are present in the second. Chromitite layers (many of which are uniquely identifiable stratigraphic marker horizons) are concentrated in the Chromitiferous Zone, and define a regular stratigraphy which is continuous along strike. Within this zone, continuity of even millimetre scale stratigraphic units is remarkable, extending for the full 1 km of strike length that was mapped. The Sill has been subject to greenschist facies regional metamorphism which has resulted in complete alteration of the primary mineralogy, although with perfect preservation of original textures. These textures indicate a quiescent magma chamber in which soft sediment deformation processes commonly operated. Evidence also exists for migration of late stage magmatic fluids, and the development of supercooled magma/magmatic fluid.

Faults are common, producing offset, loss and repetition of layers which will be of significance to any attempts at mineral exploitation.

INTRODUCTION

As part of the Geological Survey of Canada's contributions to the Canada-Manitoba Mineral Development Agreement 1984-1989, geological mapping was conducted on the Bird River Sill at the Chrome property during the summers of 1985 through 1988. The objective of the MDA project was to document the nature, distribution, and origin of chromitite layers and subeconomic concentrations of PGE by detailed mapping at a variety of scales to illustrate significant elements of the stratigraphy of the Sill. The Chrome property was selected since it provides the best exposure and the thickest and most complete section of the Sill.

This open file report describes the geology at this locale as observed in outcrop, and consists of this set of descriptive notes and six map sheets: a 1:2000 scale map of the Chrome property covering the entire cross section of the Bird River Sill and immediate host rocks (approximately 1 km of strike length); a 1:500 scale map of part of the basal portion of the Sill and immediate footwall (approximately 200 m strike length); and four 1:200 scale map sheets of part of the Chromitiferous Zone and immediately adjacent rocks (totalling approximately 600 m strike length).

ACKNOWLEDGMENTS

I am very pleased to acknowledge the work of several excellent student assistants, without whose help the mapping would have been very much less extensive. They are P.L. Schwann (1986, 1987) for extensive detailed mapping and assistance in the property mapping; J.S. Scoates (1986) for detailed mapping; K.A. Hudson (1987) for detailed mapping and assistance in the property mapping; W.J. Russell (1987) for the property mapping of the Mafic Series; and W. Donaldson (1985) and W. Lewis (1988) for short term assistance. R.F.J. Scoates introduced me to the area, and has provided some infill information on the property map and helpful discussions on the Mafic Series rocks. O.R. Eckstrand and D.G. Richardson provided critical reviews which improved the report. Mrs. O. Zeemil, holder of the mineral rights in the map area, gave permission to work on her property.

LOCATION & GEOLOGICAL SETTING

The Bird River Sill is a differentiated ultramafic to mafic layered intrusion of Archean age (2745$\pm$5 Ma; Timmins et al., 1985) which intrudes the Rice Lake Group of the Bird River greenstone belt (Trueman, 1980). The Bird River greenstone belt has previously been included as part of the English River Subprovince, but recent revision by Card and Ciesielski (1986) redefines it separately as the Bird River Subprovince of the Superior Province. The rocks consist of a supracrustal sequence of Archean volcanic and sedimentary rocks intruded by synvolcanic intrusions (including the Bird River Sill), the whole of which has been bounded by syn- and post-tectonic plutons and deformed to produce an eastward plunging anticline that wraps around the Maskwa Lake batholith (Trueman, 1980). As a result of this deformation, the Bird River Sill has been broken into several discrete blocks by cross faulting. Figure 1 shows the location of the Bird River Sill and the Chrome property placed in its geological setting. Table 1 shows the stratigraphic context.

The Chrome property is easily accessed from Lac du Bonnet by provincial highways 313 and 315. At a point 12.2 km east of the first Bird River crossing, a bush road runs north from 315 for 0.9 km to the Chrome property. The road was passable by four wheel drive vehicle in 1988, but the bridge over Peterson Creek may soon be washed out.

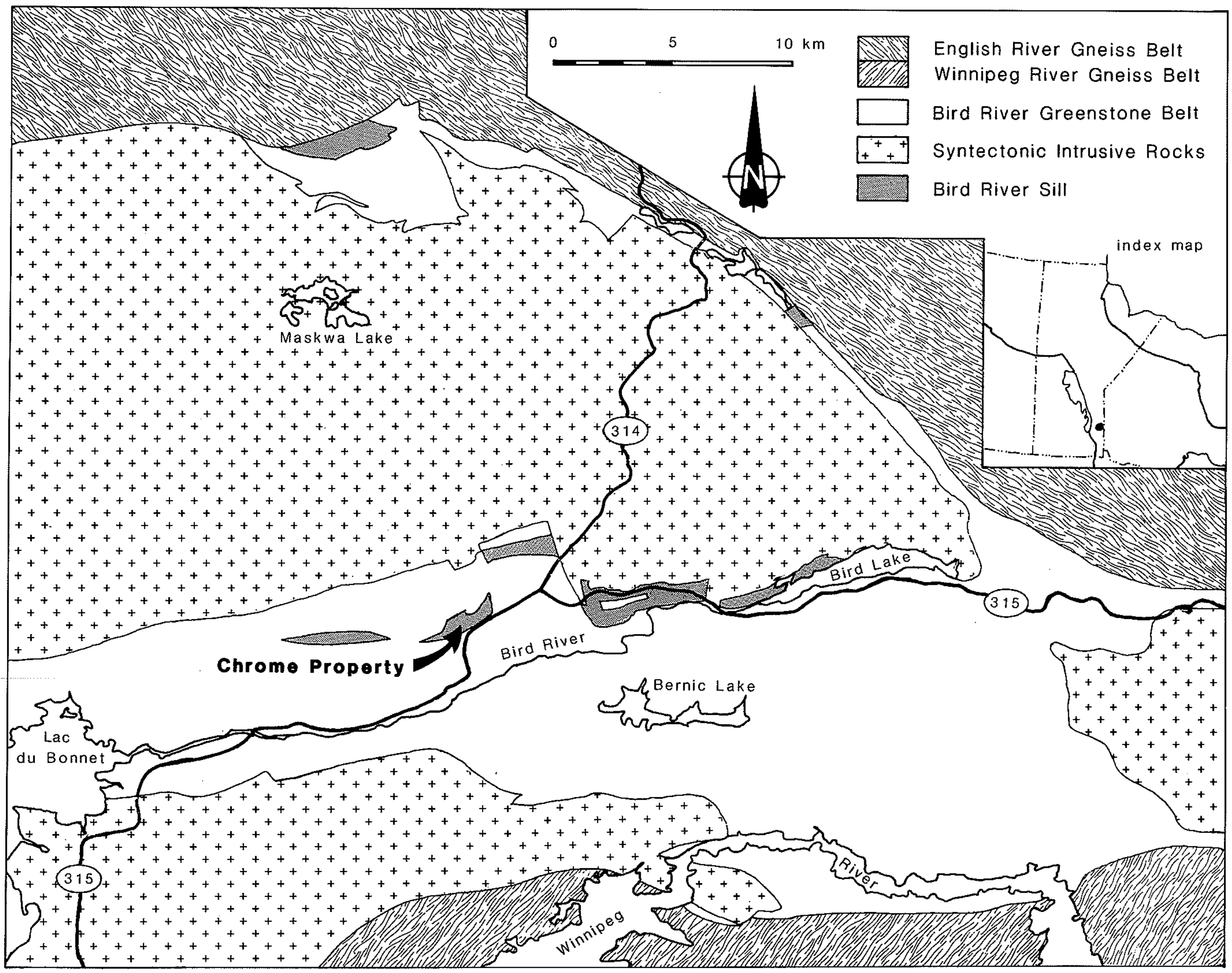


Figure 1 Location and geological setting of the Bird River Sill.

Table 1. Table of formations, Bird River belt

	Supracrustal Rocks			Intrusive rocks	Metamorphism	Deformation
ARCHEAN				pegmatite, aplite, pegmatitic granite	M_4	D_4
				Lac du Bonnet Batholith	M_3	D_3
				Maskwa Lake Batholith Marijane Lake Batholith	M_2	D_2
	Rice Lake Group	Booster Lake Formation	greywacke, mudstone			
		Flanders Lake Formation	lithic arenite and conglomerate		M_1	D_1
		Bernic Lake Formation	basaltic to rhyolitic flows and clastic derivatives	gabbro, diorite, quartz-feldspar porphyries, granodiorite		
		Peterson Creek Formation	rhyolitic flows and clastic equivalents	Bird River Sill gabbro		
		Lamprey Falls Formation	basalt			
		Eaglenest Lake Formation	volcanic wacke			

after Trueman, 1980

PREVIOUS WORK

The earliest work in this area dates back to Tyrell (Tyrell & Dowling, 1900), who conducted the first reconnaisance survey. Cooke (1921) first applied the name "Oiseau (Bird) River sill" to gabbros of the area, and Wright (1924) mapped several bodies of peridotite and gabbro corresponding to the currently recognized block-faulted segments of the Bird River Sill, which he suggested were separate intrusions. Acceptance of the Bird River Sill as a single, tectonicly deformed intrusion did not come until discovery of the chromite deposits (Bateman & Brownell, 1942). Trueman (1980) gave a thorough summary of work done in the Bird River belt, which included descriptions of the Sill by Osborne (1949) and Trueman (1971), and of the chromite composition by Gait (1964). Work since that date includes evaluations of chromite ore reserves (Bannatyne & Trueman, 1982; Watson, 1985); PGE potential at the Chrome property (Theyer, 1985; Scoates et al.,1988); platinum group mineral inclusions in chromite (Talkington et al., 1983; Ohnenstetter et al., 1986); preliminary stratigraphic subdivision of the ultramafic rocks (Scoates, 1983); and a study of the upper portion of the Sill (Dmytriw, 1984). In addition, preliminary results from the current studies were published in a GAC-MAC field trip guidebook (Scoates et al., 1986).

STRUCTURAL GEOLOGY

Although this study was not concerned with the detailed structural history of the Bird River Sill, some general comments can be made regarding structural geology at the Chrome property. A separate detailed study of the structural geology has been initiated by W.C. Brisbin, University of Manitoba. In the current study, two types or stages of deformation of the Sill rocks were recognized; synmagmatic, and postmagmatic.

Synmagmatic deformation is characterized by a generally more ductile nature (with clear parallels to soft sediment deformation in sedimentary rocks) and the absence of accompanying fracture filling and directional growth of secondary minerals (tectonic striation). Features observed include thinning, thickening, stretching, slumping, necking and boudinage of chromitite layers, as well as brittle truncation of chromitite layers. Additional soft sediment-like deformation features include "drop and sag" and "load cast" structures. Some of these features were documented by Scoates et al. (1986). This type of deformation must have occurred before the magma was completely crystallized and while the crystal mush was still capable of flow.

Tectonic disruption is clearly brittle in character, with accompanying fracture filling. It commonly occurs as schistose faults and shear zones, either simple or anastamosing, with both sinistral and dextral displacement, that cut across magmatic layering. Some fault zones are wide (a few metres) and contain rotated blocks. Others produce both omission and duplication of layers. This type of deformation must have occurred after the magma/crystal mush had thoroughly solidified so as to fracture in a brittle manner.

Within the limits of the Chrome property, all strata are tilted to a subvertical, south-facing attitude. No other folding was recognized.

DESCRIPTION OF MAP UNITS

The following description of map units is based principally on field observations, augmented by some cursory thin section examination. It should be noted that the Bird River greenstone belt has undergone three ages of metamorphism, generally of greenschist facies but locally to granulite facies (Trueman, 1980); as a result, all rocks

have been recrystallized to various degrees. For simplicity, the prefix "meta" is omitted but implied for the names of all rocks described in this report.

LAMPREY FALLS FORMATION (MAP UNIT 1)

The Lamprey Falls Formation was not mapped in this study except to delineate the basal margin of the BRS, and only a few outcrops of these rocks were seen. The description which follows is summarized from Trueman (1980).

The Lamprey Falls Formation consists essentially of mafic volcanic rocks and related hypabyssal intrusions, dominated by pillowed basalt but also including tuff, hyaloclastite, aquagene breccia, megacrystic, porphyritic and amygdaloidal basalt, iron formation and gabbro. In the map area, only fine grained pillowed basalt and a medium grained, diabasic textured basalt/gabbro were seen. The unit was distinguished by its black colour in weathered outcrop.

BIRD RIVER SILL (MAP UNIT 2)

The Bird River Sill is a layered intrusion, composed of several varieties of peridotite and gabbro (distinguished on the basis of textures observed in the field), chromitite, diorite and trondhjemite.

Subdivision of the Bird River Sill used here is based on the stratigraphy proposed by Scoates (1983) with refinements and additions as required. The nomenclature for subdivision of the Sill follows the format suggested by Irvine (1982).

The first order subdivision is into three series: a lower Ultramafic Series (approximate thickness 200 m), a Transition Series (approximate thickness 22 m) and an upper Mafic Series (approximate thickness 600 m). Each series has been further subdivided into zones based on mappable differences in lithology and textures. Where warranted, zones have been broken down into subzones. In the case of the Chromitiferous Zone the chromitite layers (each uniquely identifiable by lithological characteristic or stratigraphic relation) have been identified with group and member names. The nomenclature used in this report is presented in Table 2.

ULTRAMAFIC SERIES (MAP UNIT 2A)

The Ultramafic Series consists almost entirely of peridotite, with subordinate chromitite, gabbro, and a rock transitional between peridotite and gabbro (provisionally called troctolite). It is divided into five zones, described below.

Table 2. Stratigraphic subdivision of the Bird River Sill

		Zone	Description
BERNIC LAKE FORMATION			mafic volcaniclastics containing boulders of Upper Gabbro Zone; clastic sedimentary and volcanic rocks
unconformity (?)			
BIRD RIVER SILL	MAFIC SERIES	Upper Gabbro Zone (150 m)	gabbro; anorthositic gabbro
		Trondhjemite Zone (40-90 m)	trondhjemite; diorite; aplite dikes
		Quartz Gabbro – Diorite Zone (60-120 m)	massive and porphyritic diorite; quartz bearing and "chicken track" gabbro; aplite dikes
		Xenolith Zone (60-120 m)	blocks of medium to coarse grained gabbro in matrix of medium to coarse grained gabbro; glomeroporphyritc, pegmatitic and mela- gabbro
		Lower Gabbro Zone (90-220 m)	anorthosititc, pegmatitic, heterogeneous and mela- gabbro
	TRANSITION SERIES	Upper Peridotite Zone (6-12 m)	knobby peridotite; pyroxenite
		Gabbro Zone (8-9 m)	troctolite; gabbro
		Lower Peridotite Zone (3-7 m)	knobby peridotite
	ULTRAMAFIC SERIES	Chromitiferous Zone (40-60 m)	peridotite; chromitite (Lower, Disrupted, Lower Main, Banded & Diffuse, Upper Main and Upper Paired groups)
		Massive Peridotite Zone (40-50 m)	knobby and smooth weathering peridotite
		Layered Zone (40-60 m)	Gabbro subzone - troctolite: gabbro Layered subzone - knobby and smooth weathering peridotite; layered peridotite - chloritite Basal subzone - foliated and knobby peridotite: minor chromitite
		Megadendritic Zone (30-50 m)	megadendritic, knobby and smooth weathering peridotite
intrusive contact		Contact Zone (2 m)	fine grained plagioclase bearing peridotite
LAMPREY FALLS FORMATION			basalt; gabbro

MAFIC DIKE ? ? ?

Contact Zone (map unit $2A_1$)

The contact of the Bird River Sill with basalt and gabbro of the underlying Lamprey Falls Formation was only observed on the Chrome property at one exposure (in the north part of Sheet 5). The outcrop is rubbly and the contact hard to discern.

The Contact Zone consists of a 2 to 5 m thick section of orange weathering, dark grey, very fine grained rock which coarsens to medium grained a metre up section. The contact with the overlying Megadendritic Zone is gradational, and Contact Zone rocks near this contact consist of pseudomorphically serpentinized fine grained olivine cumulate (0.3-1 mm) with resistant weathering clinopyroxene oikocrysts (up to about 1cm).

Megadendritic Zone (map unit $2A_2$)

The Megadendritic Zone is well exposed across the Chrome property, and has a thickness of 30 to 50 m. The rock types in this zone include a random mixture of peridotites distinguished by the appearance of their weathered surface: "smooth", "knobby" or "megadendritic". All consist of fine grained cumulus olivine (<2 mm) with accessory chromite (<3%, <0.5 mm diameter) and variable amounts of pyroxene. Smooth weathering peridotite contains <10% pyroxene oikocrysts; knobby weathering peridotite contains 10 to 50% pyroxene oikocrysts which weather resistantly, producing a rough knobby surface. Megadendritic peridotite is a knobby weathering peridotite in which pyroxene is organized into intersecting "sprays" of curved dendrites (Fig. 2). All types exhibit the characteristic rusty orange weathering of ultramafic rocks, with chocolate coloured knobby pyroxene.

Layered Zone (map unit $2A_3$)

The Layered Zone consists of a variety of rock types, and is best exposed in the northwestern part of the map area, and has a thickness of about 30 to 60 m. This apparent thickness may have been abbreviated by faulting. It has been subdivided into three subzones.

The **Basal subzone (map unit $2A_{3B}$)** is from 5 to 15 m thick, and is composed of peridotite (weathering to typical peridotite orange colour). A strong NE trending foliation is developed as a result of shearing and faulting. The rock contains disseminated sulphide blebs (to 1 cm diameter) which give rise to a diffuse, splotchy hematitic rust on the weathered surface. Chemical analysis has given PGE values of up to 170 ppb Pt and 390 ppb Pd, corresponding to the lower PGE enrichment of Theyer (1985; western cut, 35 to 52 m). Chromitite is present as a pseudo layer, consisting of a 1 cm thick, wispy, discontinuous layer (Basal chromitite) and

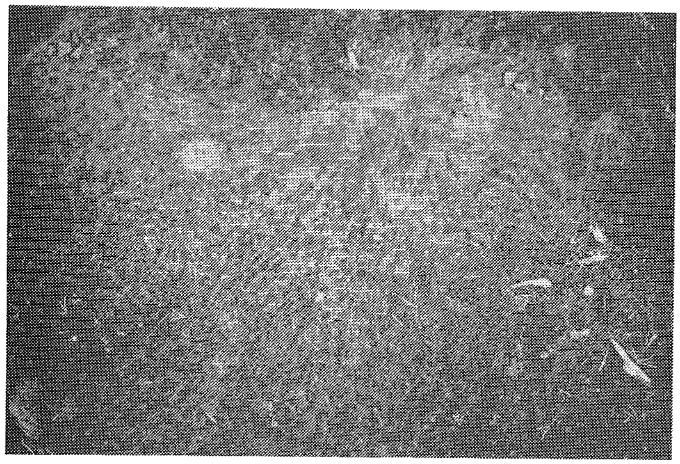


Figure 2 Example of megadendritic peridotite. Field of view is approximately 1.5m across. GSC 204917-C.

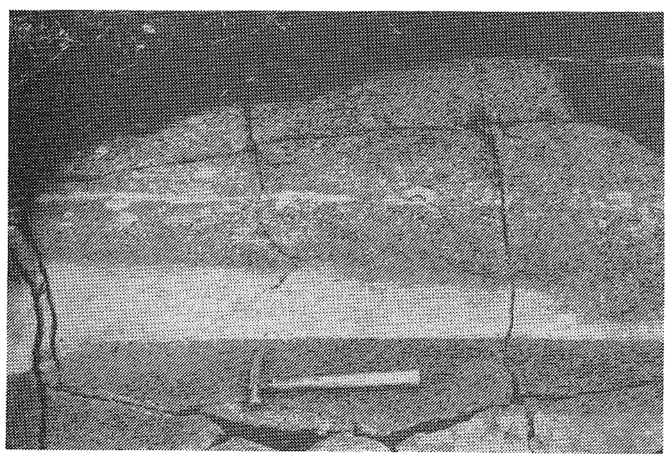


Figure 3 Massive chlorite layers and eggs in knobby peridotite, Layered Zone. Pick of hammer head (17cm) points to stratigraphic top. GSC 204887-M.

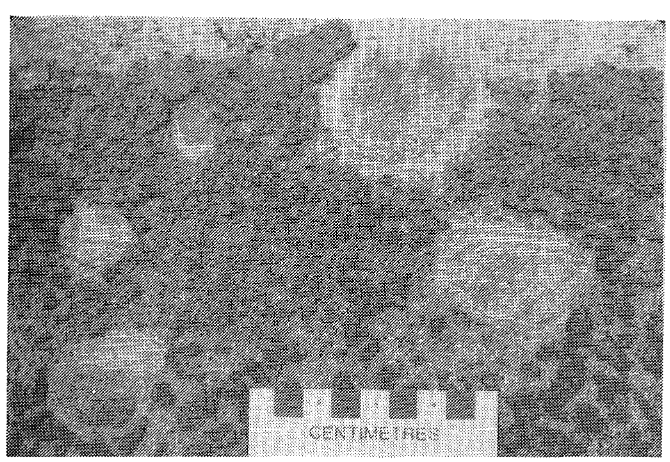


Figure 4 Chlorite eggs in knobby peridotite (detail from upper left, Figure 3). Top of photo is stratigraphic top. GSC 204887-D.

sporadic pods (up to 20 x 200 cm) along strike at the same stratigraphic position.

The **Layered subzone (map unit $2A_{3L}$)** is 20 to 35 m thick, and includes several rock types. It consists of massive peridotite at the base, overlain by smooth weathering and knobby weathering peridotite in poorly defined thick alternating layers (approximately 0.5 to 1 m), and overlain uppermost by knobby weathering peridotite and massive chlorite rock (called meta-dunite in the field) in sharply defined thin alternating layers (10 to 150 cm). Changes from massive to poorly layered to well layered rocks are gradational. The terms smooth and knobby peridotite refer to the texture of the weathered surface, reflecting the amount of original pyroxene present.

The massive chlorite layers are a unique and interesting feature of this unit. On the weathered surface they are smooth and recessive, have a pale greenish turquoise colour, and feel slightly talcose to the touch. They have a distinctive fish scale-like texture (interpreted as the overprint of shearing on the more ductile chlorite) but no relict textures are distinguishable. They generally have knife sharp and ruler straight lower contacts with underlying knobby peridotite, but upper contacts are gradational over 1 to 10 cm and may be irregular or wavy. Some of the massive chlorite rock contains a few per cent of fine grained pyroxene which weathers resistantly, giving a fine-grained equivalent of knobby peridotite. The implication is of a rock lying between the compositional end members of "dunite" and peridotite. The layers are occasionally seen to pinch out into massive knobby peridotite, suggesting that they may have originally been intrusive into the peridotite, or have been synmagmatically stretched and necked. Figure 3 shows some of these features.

Another interesting feature of this subzone is the occurrence of what Scoates (1983) called "circular to elliptical dunite inclusions", named "egg" structures here. Although not unique to this subzone, they are most extensively developed here. They consist of spheroidal to elliptical balls (usually 2 to 10 cm, occasionally up to 20 cm) of the same massive chlorite material as in the "dunite" layers, scattered throughout the Layered subzone. They are usually contained in knobby peridotite, but may overlap contacts with the chlorite layers. Where chlorite layers pinch out, eggs can be seen along strike of the thinning layer, as if they are a result of a necking down or boudinage of the layer; but their presence at layer contacts argues against this single explanation. The eggs themselves have contacts which grade sharply over 2 to 5 mm from massive chlorite to knobby peridotite, often with a discontinuous single crystal thick rind of chromite. Figures 3 & 4 show the nature of the eggs and their relationship to layering. No obvious and simple explanation for their origin is advanced here, but several possibilities have been entertained: that they are blebs of an immiscible magma; that they are due to the pinchout of layers; or that they represent either earlier megacrysts or blocks of disrupted layer material emplaced by a later magmatic event.

The **Gabbro subzone (map unit $2A_{3G}$)** is comprised of gabbro and a rock transitional from the ultramafic rock of the Layered subzone (provisionally called troctolite). Both rock types are massive textured. Faults occur at the upper contact (which is a fault contact with the overlying Massive Peridotite Zone wherever exposed) and at the lower contact with the Layered subzone (which is only exposed in one outcrop as an unfaulted, igneous contact). The subzone is about 15 m thick, but almost certainly has been truncated by faulting.

The gabbro weathers a dirty greyish white colour, showing dark grey on a broken fresh surface. Cumulus plagioclase laths are clearly discernible on the smooth surface of sampling sawcuts in outcrop or on the polished surfaces of hand specimens, with a heavy sprinkling of mafic minerals (presumably secondary amphibole after original pyroxene). The transitional rock ("troctolite") lies at the base of the Gabbro subzone, and represents the gradation from distinctly ultramafic rock of the Layered subzone to distinctly mafic rock of the Gabbro subzone. It weathers to a splotchy orange-white colour, ranging in shade from predominantly orange with white at the more ultramafic base, to white with subordinate orange in the overlying more mafic rock. This presumably reflects a change in original mineralogy from more ultramafic (orange) to more mafic (white).

Contacts within the Layered Zone are gradational. Although definition of subzones is somewhat arbitrary, they have been defined on the basis of the following criteria.

The most distinctive characteristic of the Basal subzone is a strong foliation. Weathered sulphides, smooth weathering surface and the presence of chromite concentrations are additional important criteria. The transition from Basal subzone to massive peridotite of the Layered subzone may represent simply the difference between a sheared peridotite (Basal subzone) and an unsheared peridotite (Layered subzone). The presence of sulphides and chromitite argue for distinguishing the Basal subzone as a separate unit, although sulphides and chromite pods also occur (although much more rarely) in the lower parts of the Layered subzone. Similarly, the stratigraphic extent of layering is difficult to pinpoint exactly. Because layering is poorly defined in the lower part of the Layered subzone, the position of its lower contact is rather arbitrary. Since the foliation and predominance of sulphide and chromite are readily identified in the detail map area, the extent of the Basal subzone is defined on the basis of their combined presence.

A comparable problem exists in defining a contact between the Layered and Gabbro subzones. In this report that contact is simply defined as the top of the uppermost massive chlorite layer in the underlying Layered subzone.

The contacts thus defined have proven workable, as they are easily recognized and mapped in the field.

Massive Peridotite Zone (map unit $2A_4$)

The Massive Peridotite Zone is 40 to 50 m thick. Alteration minerals after cumulus olivine (1 to 5 mm) weather pale green to orange, whereas patchy pyroxene oikocrysts weather resistantly to dark brown. Immediately overlying the faulted lower contact (Sheet 5) the peridotite is texturally variable, with knobby weathering, weakly megadendritic or oikocryst poor smooth weathering pods, similar to the Megadendritic Zone (Fig. 5). This passes upwards into a mixture of pale green weathering, oikocryst poor peridotite with a dense lacework of magnetite rich serpentinization veins; and "splotchy peridotite", a massive orange weathering olivine cumulate rock with patchy pyroxene oikocrysts (Fig. 6). Pyroxene oikocrysts of the knobby or megadendritic peridotites are about 1 cm and weather as numerous small rough knobs while those of the patchy type are concentrated in fewer but larger blotches of 2 to 10 cm. The amount of pyroxene present is comparable in the two types, but the form is distinctly different. The splotchy peridotite continues up section to the first chromitite layer (the lower thin member of the Lower Group chromitites, Lltn), at the base of the overlying Chromitiferous Zone.

The distribution of exposed rock types in Sheet 5 suggests possible fault dislocations. Consequently the calculated thickness of this zone may represent a minimum.

Chromitiferous Zone (map unit $2A_5$)

The Chromitiferous Zone is 40 to 60 m thick and consists of peridotite and chromitite in alternating layers of variable thickness. The peridotite is similar to splotchy peridotite of the Massive Peridotite Zone: a massive black rock which weathers pale green or typical rusty orange with resistant weathering dark brown pyroxene oikocrysts. It is composed of serpentine pseudomorphs after original cumulus olivine (1 to 5 mm), with fine cumulus chromite (0 to 5%; 0.25 to 0.5 mm) and patchy pyroxene oikocrysts (up to 40%, 5 to 20cm) interstitial to the cumulus olivine.

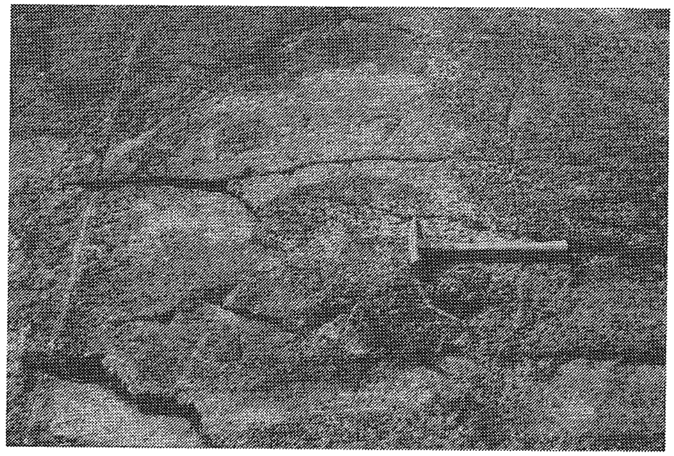


Figure 5 Pods of smooth weathering, pyroxene poor peridotite in knobby peridotite, Massive Peridotite Zone. Pick of hammer head (17cm) points to stratigraphic top. GSC 204887-E.

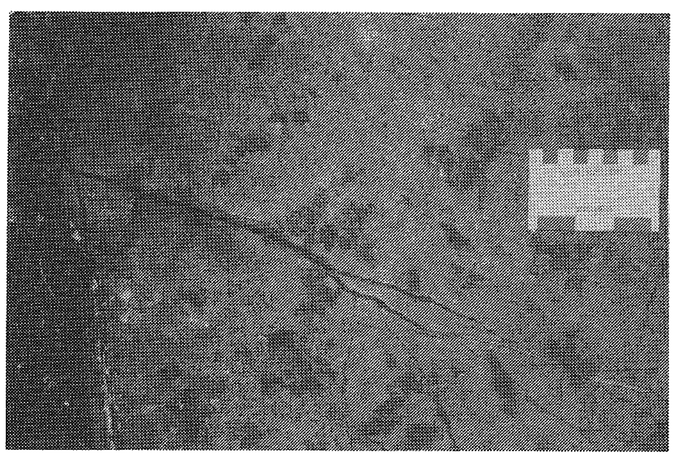


Figure 6 Splotchy peridotite, Massive Peridotite Zone. Pyroxene oikocrysts are less abundant and larger than in knobby peridotite. GSC 204887-C.

Chromitite was classified into two types: dense chromitite and diffuse chromitite. Dense chromitite consists of a concentration of discrete cumulus chromite (30 to 60%; 0.25 to 0.5 mm) with intercumulus serpentine + chlorite. In outcrop, dense chromitite appears as a solid black layer which on lichen-free outcrop stands out clearly against lighter peridotite. Diffuse chromitite consists of cumulus chromite + cumulus olivine in approximately equal proportions. These rocks represent a continuum of olivine/chromite proportion:

peridotite	= olivine-chromite cumulate;	intercumulus pyroxene
	60-90% 1-5%	10-40%
diffuse chromitite	= chromite-olivine cumulate;	intercumulus material
	30% 30%	40%
dense chromitite	= chromite cumulate;	intercumulus chlorite + serpentine
	50%	50%

The thickness of individual chromitite layers, their particular characteristics, and the stratigraphic interval between them is remarkably consistent over the 600 metres of strike length mapped. Practically any exposure of at least two chromitites is sufficient to precisely identify the position within the stratigraphy, either by their unique characteristics or in conjunction with their juxtaposition. To aid in identification, a nomenclature was developed whereby chromitites which occur together as a stratigraphic package were termed groups, and individual chromitites were termed members (in keeping with the format proposed by Irvine, 1982). Abbreviations for these terms identified groups by upper case letters and members by lower case. Terminology for the complete Chromitiferous Zone is shown in figure 7. The stratigraphy is a refinement of that proposed by Scoates (1983), with his "suites" renamed as groups. The following paragraphs describe each chromitite group.

The **Lower Group** contains two member chromitite layers, the lower thin (Lltn) and upper thick (Lutk), and the intervening peridotite. This Group typically consists of 2 cm of dense chromitite overlain by 40 cm of peridotite, in turn overlain by 10 cm of dense chromitite (approximate thicknesses). Figure 8 (in map pocket) shows the variation in thickness along strike of the two chromitites and the intervening peridotite and figure 9 shows a typical exposure. Additional features which may occur include bifurcation of Lltn; a "spongy" top to Lutk (a result of silicate inclusions within the dense chromitite) and a "lacey" texture to Lltn (a result of abundant silicate

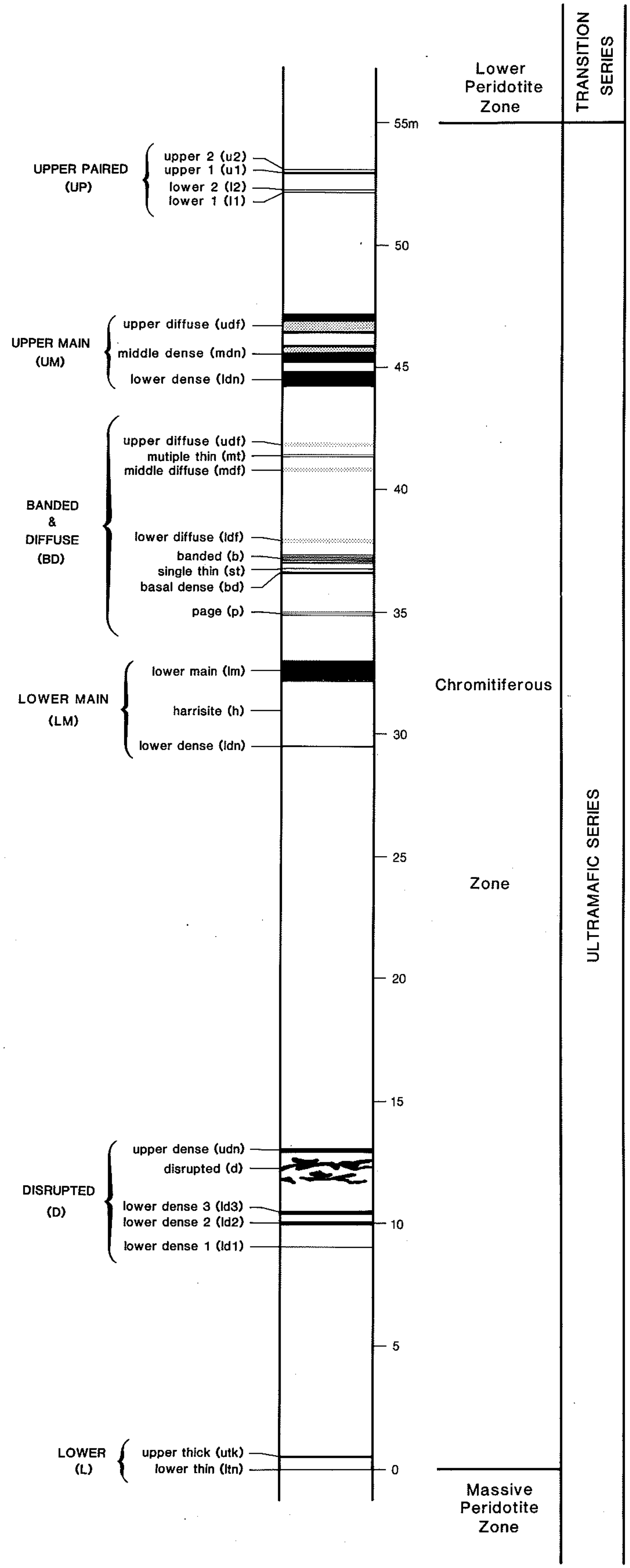


Figure 7 Detailed stratigraphic column of the Chromitiferous Zone.

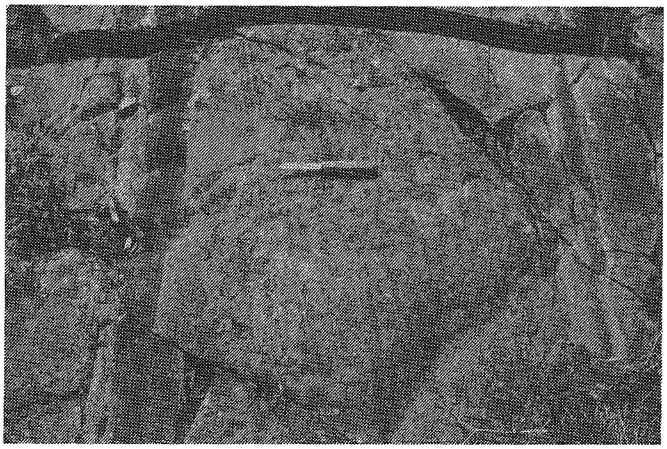


Figure 9 Typical section of Lower Group chromitite, Chromitiferous Zone. Knife (about 15 cm long) points to stratigraphic top. GSC 204887-O.

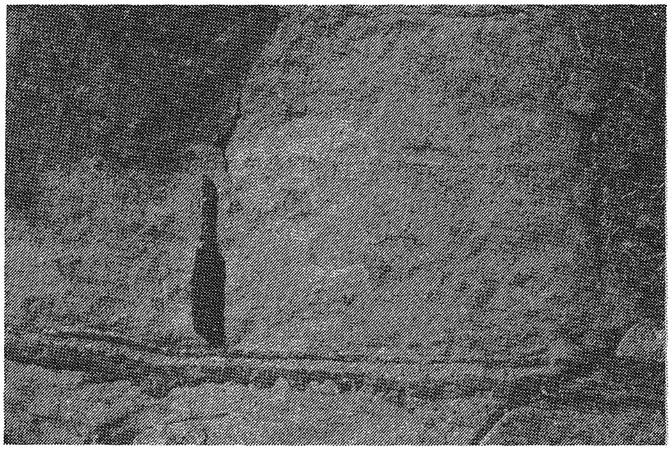


Figure 11 Dld1 chromitite, Chromitiferous Zone. Knife (16 cm long) points to stratigraphic top. GSC 204887-S.

inclusions to which the thin chromitite is interstitial). Contacts between chromitite layers and enclosing peridotite are generally sharp and distinct, but may locally be gradational over 1 to 2 cm.

The **Disrupted Group** overlies the Lower Group, separated by 4 to 13 m of medium grained peridotite (average 8.5 m). It consists of four distinctive chromitite layers (Dld1, Dld2, Dld3 and Dudn) with intervening peridotite, and a contained interval of mixed peridotite and chromitite (Dd). Figure 10 (in map pocket) shows the along-strike variation of the Group. The lower dense 1 member (Dld1) is variable from a single dense chromitite layer (about 1 to 3 cm thick) to a 1 to 4 cm interval of thin chromitite layers in peridotite. It is commonly sinuous, disrupted or discontinuous, and can have a "lacey" appearance (Fig. 11). It is overlain by about 1 to 1.5 m of peridotite up to the lower dense 2 member (Dld2). The Dld2 layer is a 10 to 20 cm thick dense chromitite with sharp contacts and a diagnostic "spongy" texture (Fig. 12) resulting from 30 to 50% silicate inclusions (about 1 cm diameter). It is overlain by 20 to 50 cm of peridotite and the lower dense 3 member (Dld3). The Dld3 layer consists of 10 to 20 cm of dense chromitite with sharp contacts. It is commonly irregular, displaying sinuous undulation, pinching and swelling, and bifurcation of the layer. It is locally disrupted, and in places merges with Dld2. The overlying disrupted member (Dd) consists of 1 to 3.5 m of peridotite and enclosed chromitite pods and layers (Fig. 13). The chromitite in Dd characteristically displays variable modes of disruption ranging from weakly disrupted, braided layers (1 to 2 cm thick) through discontinuous, wispy stringers to a collection of discrete pods. This progression suggests increasing degrees of disruption of an original chromitite layer(s) at a synmagmatic stage. The resulting shapes of chromitite layers (e.g. Fig.14) are analogous to those of drop and sag structures of heavy mineral layers in fluidized clastic sediments (Stewart, 1963). The Disrupted Group contains many additional examples of features interpreted as arising from soft sediment-like disruption. These include "drop and sag" structures (in Dd at many locations) and slump structures (in Dld2 at 160W/83N, map Sheet 3; Dld2 at 315W/75N, map Sheet 4; and Dudn at 285W/75N, map Sheet 4). These types of layer disruption, the general stratigraphic relationships and the unique appearance of Dld2 are the most important diagnostic features in distinguishing the Disrupted Group. The Disrupted Group is capped by the upper dense member (Dudn). It consists of a 10 to 25 cm thick dense chromitite layer with sharp contacts, commonly with a "spongy" textured top (Fig. 15).

The **Lower Main Group** overlies the Disrupted Group, separated by 9 to 22 m (average 16.5) of peridotite. It consists of two chromitite layers and intervening

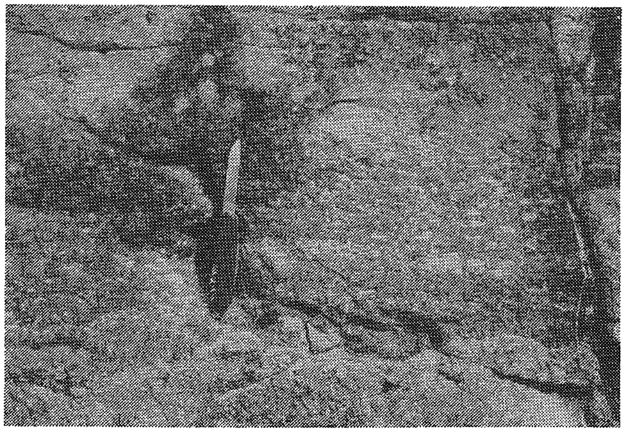
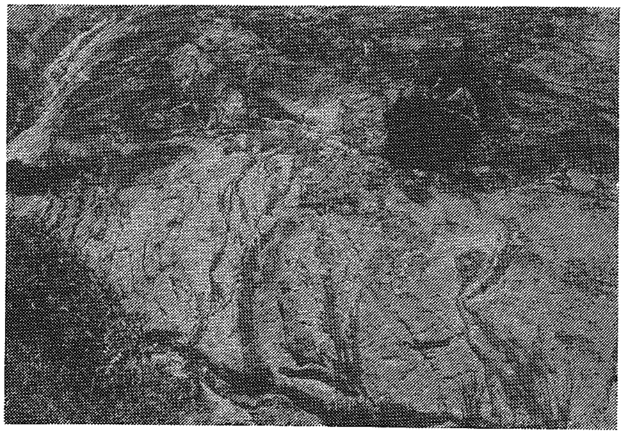
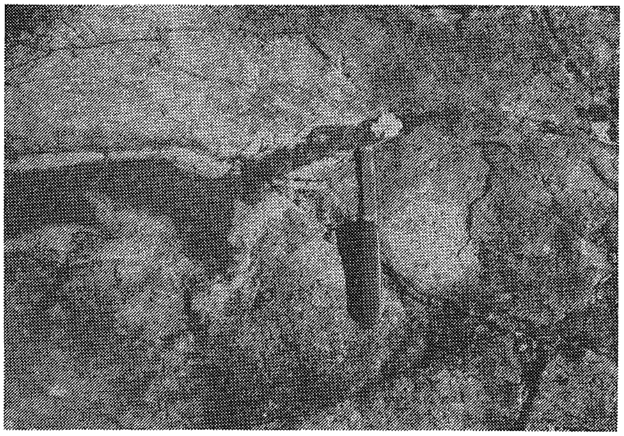
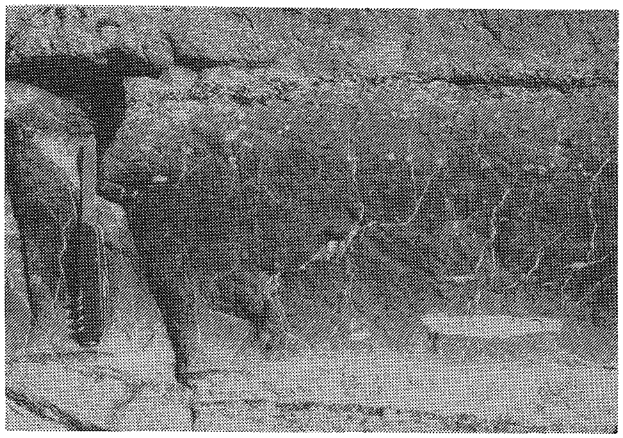





Figure 12 (upper left) Typical Dld2 chromitite, Chromitiferous Zone, showing the spongy texture caused by silicate inclusions. The blackened patch under the knife blade is due to weathering. Knife (16 cm long) points to stratigraphic top. GSC 204887-W.

Figure 13 (upper right) Dd chromitite, Chromitiferous Zone, showing typical disrupted layers. In other locales, the disruption is more extreme. Knife (16 cm long) points to stratigraphic top. GSC 204887-P.

Figure 14 (lower left) "Drop and sag" structure developed within the Disrupted Group, Chromitiferous Zone. Knife (16 cm long) points to stratigraphic top. GSC 204917.

Figure 15 (lower right) Dudn chromitite, Chromitiferous Zone, showing typical "spongy" textured top (due to silicate inclusions) and dense chromitite base. White veinlets within the chromitite are interpreted to be serpentine filled post-magmatic fractures. The white pod in chromitite (lower right) is a rare larger pod of silicate. Knife (16 cm long) points to stratigraphic top. GSC 204887-Q.

peridotite. Figure 16 (in map pocket) illustrates the variation along strike of the Lower Main Group. The lower chromitite is the lower dense member (LMldn), 3 to 8 cm thick (average 6 cm). It is overlain by 130 to 480 cm of distinctive harrisitic peridotite (discussed below). The upper chromitite is the lower main member (LMlm), a 60 to 80 cm thick dense chromitite often with layers of diffuse chromitite in the lower 5 to 30 cm.

Harrisitic peridotite can occur throughout the Chromitiferous Zone as pods or patches (tens of centimetres in size), but it is only in the Lower Main Group that it is extensively developed as a continuous, mappable unit. Scoates (1983) called this peridotite "coarse grained to locally pegmatitic" and referred to the "pseudo-harrisitic pattern" of elongate olivine oriented perpendicular to chromitite layering. The term "harrisite" is used here for peridotite which is coarse grained (olivine > 1 cm) and contains skeletal olivine (hollow cores and euhedral terminations) which is elongate and commonly perpendicular to layering (Fig. 17). The important feature which distinguishes harrisite (as used here) from a merely coarse grained peridotite is the presence of skeletal form of the olivine. Bird River Sill harrisite is consistent with Donaldson's (1977) redefinition of harrisite: it has >25% olivine, with coarser grain size than adjacent cumulates, and has skeletal shapes. The rocks from Rhum originally described by Harker (1908) as harrisite are similar in that they comprise 75 to 80% elongate olivine; but the Bird River harrisites have blockier, more nearly equant olivine compared to the blade-like olivine in the Rhum harrisites.

Contacts between chromitite and peridotite are sharp and distinct. The LMldn commonly exhibits forms analagous to the load casts produced by soft sediment deformation (discussed below). The upper contact of the LMlm is generally ruler straight, but the lower contact may take either of two forms: straight, with the basal diffuse chromitite layers present, and underlain by normal medium grained peridotite (Fig. 18a); or irregular, with the diffuse chromitite layers absent, commonly a thinning of the LMlm (eg 200E/50N on map Sheet 1) and generally harrisitic peridotite in contact with overlying LMlm (Fig. 18b). In many places where the contact is irregular, protrusions of LMlm (up to 1 m) may droop down into the harrisitic peridotite. If harrisitic peridotite represents a new and hotter magma pulse or crystallization from a supersaturated magma (as suggested by Donaldson, 1974 and 1977), then partial melting of the inter-chromite material could occur, making the base of the chromitite more plastic and allowing it to form drooping sag structures.

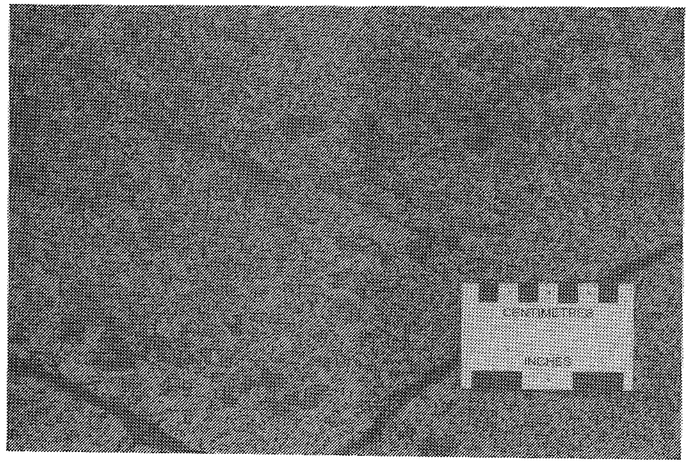
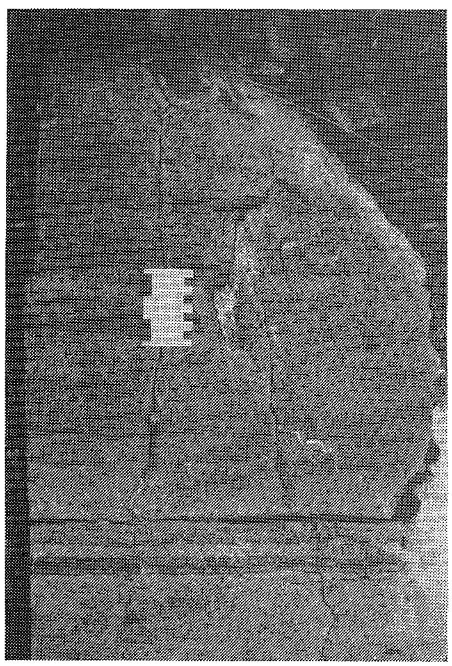


Figure 17 Typical harrisitic peridotite, LMh unit, Chromitiferous Zone. Top of photo is stratigraphic top. GSC 203543-U.



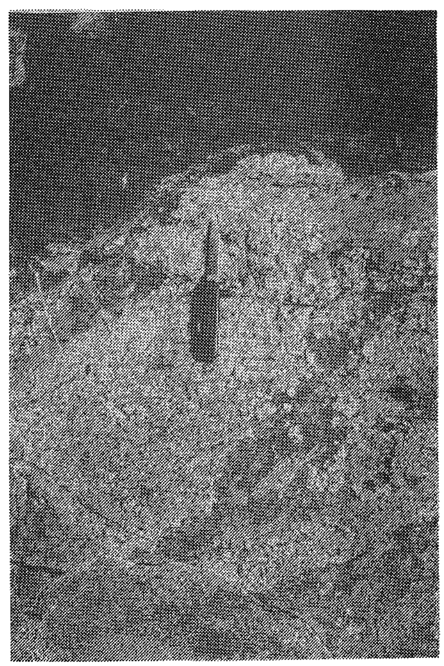


Figure 18a (left) Typical LMlm chromitite, Chromitiferous Zone, with straight base (containing diffuse layers) underlain by olivine cumulate. Stratigraphic top is to left. GSC 204887-A.

Figure 18b (right) Example of LMlm chromitite, Chromitiferous Zone, with irregular base slumping into underlying harrisite. Knife (16 cm long) points to stratigraphic top. GSC 204958-B-1.

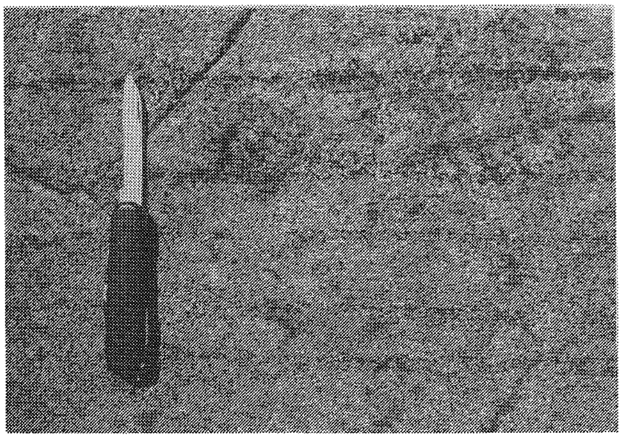
The diagnostic elements for recognition of the Lower Main Group are the harrisitic peridotite and the overlying thick chromitite (LMlm).

The **Banded and Diffuse Group** overlies the Lower Main Group, separated by 1.5 to 6 m of peridotite (average 3.6). It consists of 8 chromitite units (representing either individual layers or several consistently associated layers) and intervening peridotite. The complete stratigraphic package is normally 7 to 7.5 m thick, but is thinner where some units are not present. Figure 19 (in map pocket) shows the variation of the Group along strike.

The lowermost chromitite unit in the Banded & Diffuse Group is the Page member (BDp), which takes its name from the Page property (to the east of the Chrome) where it is best developed. At the Page property it consists of a single dense to slightly diffuse chromitite layer about 10 cm thick. At the Chrome property it consists of four or five faint, thin chromitites (ca. 1mm) within an interval of 10 to 20 cm and is present only intermittently over 450 m of strike length mapped. This contrast is shown in figure 20. It lies 140 to 220 cm below the basal dense member (BDbd).

The most readily identified interval of the Banded & Diffuse Group is that containing the basal dense (BDbd), single thin (BDst), and banded (BDb) members. This well banded interval comprises (from bottom to top): BDbd (dense chromitite, 4 to 13 cm, av 10cm), peridotite (6 to 15 cm), BDst (thin dense chromitite, 1 to 2 mm), peridotite (5 to 30 cm, average 15 cm), and BDb (about ten dense chromitite layers 1 to 3 cm each, separated by 1 to 2 cm peridotite layers, within an interval of 5 to 30 cm, average 20 cm). Diagnostic features include the regular thickness of layers, and a consistent 3 cm capping dense chromitite at the top of BDb (Fig. 21). Chromitite-peridotite contacts are sharp and commonly ruler straight. The banded interval is distinctive in appearance, present everywhere that the Banded & Diffuse Group is exposed along the 600 m strike length mapped (map sheets 1 to 4), and is remarkably consistent along strike. This banded interval is readily identified even where incompletely exposed or disrupted by synmagmatic or tectonic deformation.

Overlying the banded interval is 25 to 50 (average 40) cm of peridotite, and then an interval containing three diffuse chromitites. This interval includes the lower diffuse (BDldf, diffuse chromitite, 10 to 40 cm, average 20 cm), 230 to 350 cm of peridotite, middle diffuse (BDmdf, diffuse chromitite, 6 to 30 cm, average 20 cm), 30 to 100 cm of peridotite that contains the multiple thin (BDmt, one, two or three thin chromitites, 1 to 10 mm, within a 10 cm interval about midway between BDmdf and BDudf), and the upper diffuse (BDudf, diffuse chromitite, 10 to 30 cm,



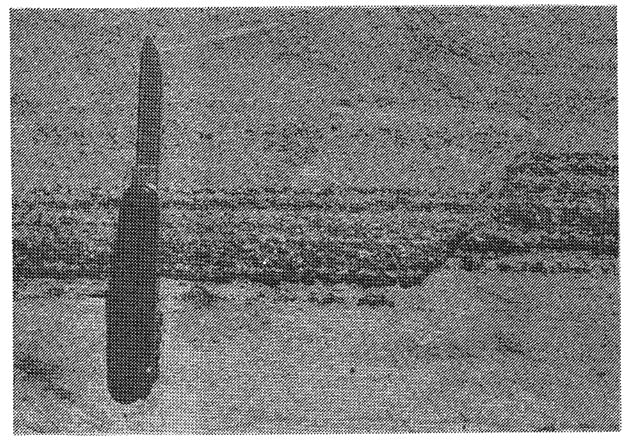


Figure 20a (left) Typical BDp at the Chrome property. Knife (16 cm long) points to stratigraphic top. GSC 204958-I-2.

Figure 20b (right) Typical BDp at the Page property, offset by a minor fault. Knife (16 cm long) points to stratigraphic top. GSC 204958-K-1.

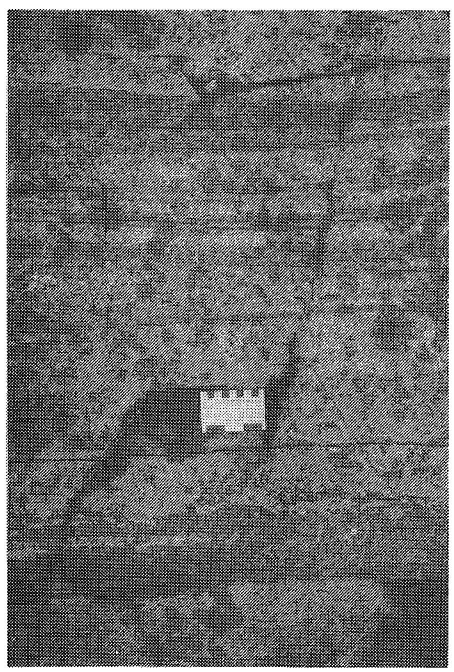


Figure 21 Typical BDbd (lowermost), BDst (2 cm below scale card) and BDb chromitites, Chromitiferous Zone. Photo top is stratigraphic top. GSC 204887.

average 20 cm). These chromitite layers are equally continuous along strike, but are not as distinctive, nor as consistent in nature as those of the underlying well banded interval. Figure 22 shows a typical example of the upper part of the diffuse section. Within the diffuse section, intervening peridotite layers are in some cases characterized by pyroxene oikocrysts which form weak pseudo-layers resulting from a concentration of pyroxene parallel to chromitite layers. BDmdf is often characterized by more diffuse boundaries, less diffuse core, and an olivine rich central layer about 2 cm thick (Fig. 23). Chromitite-peridotite contacts in the diffuse section are usually distinct but gradational over a few centimetres.

The **Upper Main Group** overlies the Banded & Diffuse, separated by 1.5 to 3 (average 2.25) m of peridotite with coarse, patchy pyroxene oikocrysts 5 to 10 cm across, which gives it a distinctive "spotted leopard" appearance (Fig. 24). The Group consists of three thick chromitite members and intervening peridotite. Figure 25 (in map pocket) shows the variation along strike of the Upper Main Group, and figure 26 a typical exposure. The lower member is the lower dense (UMldn), composed of 50 to 80 cm (average 60 cm) of dense chromitite. It is overlain by 20 to 50 cm (average 40 cm) of peridotite and the middle dense member (UMmdn), 50 to 100 cm thick (average 70 cm) of dominantly dense chromitite, with diffuse chromitite layers in the upper portion (Fig. 27). The Group is capped by an overlying 30 to 60 cm (average 50 cm) of peridotite and the upper diffuse (UMudf; Fig. 28), composed of 70 to 110 cm (average 80 cm) of dominantly diffuse chromitite, with richer (dense chromitite) and leaner (peridotite) layers. Usually diagnostic of UMudf are bounding dense chromitites, 5 to 8 cm at the base and 16 to 40 cm at the top. Contacts are generally sharp, the exceptions being occasional gradational contacts where diffuse chromitites occur. Diagnostic features of the Upper Main Group are the presence of the underlying spotted peridotite, the stratigraphic intervals, and the thick dense chromitites. Except for the LMlm (much lower in the sequence and usually associated with harrisite), no other chromitites approach the thicknesses of the Upper Main chromitites.

The **Upper Paired Group** overlies the Upper Main Group, separated by 2.5 to 7.5 (average 5.3)m of peridotite. It consists of two pairs of thin chromitites and the intervening peridotite. Figure 29 (in map pocket) shows the variation along strike of the Group, and figure 30 shows a typical exposure. The lower pair consists of 2 cm of chromitite (UPl1) overlain by 10 to 14 cm (average 14 cm) of peridotite overlain by 0.5 cm of chromitite (UPl2). The upper pair consists of 6 to 10 cm (average 8 cm) of chromitite (UPu1) overlain by 10 to 16 cm (average 12 cm) of peridotite, in turn overlain by 1 cm of chromitite (UPu2).

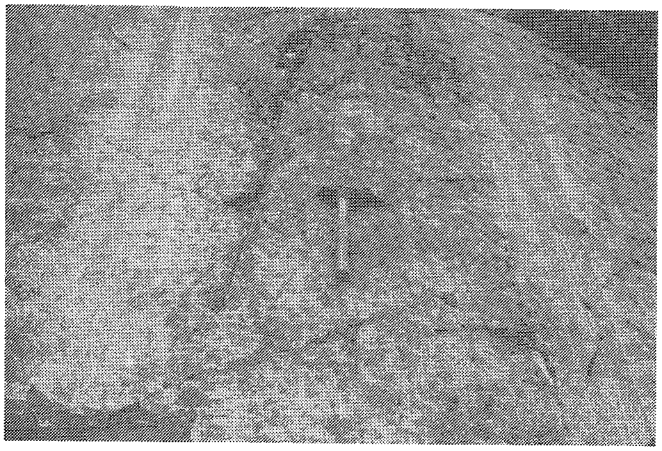


Figure 22 Typical BDmdf (at left), BDmt (under hammer head) and BDudf chromitites, Chromitiferous Zone. Pick of hammer head (17cm) points to stratigraphic top. GSC 204887-V.

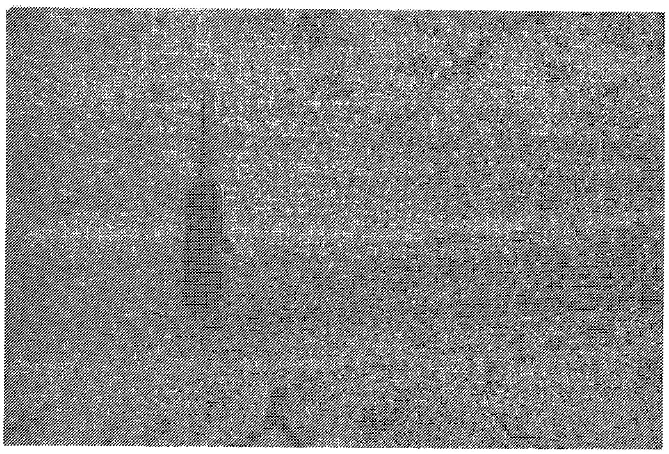


Figure 23 Detail of BDmdf, showing cumulus olivine (pseudomorphs) and chromite typical of diffuse chromitites. Medial olivine rich band (if present) is diagnostic of BDmdf. Knife (16 cm long) points to stratigraphic top. GSC 204887-I.

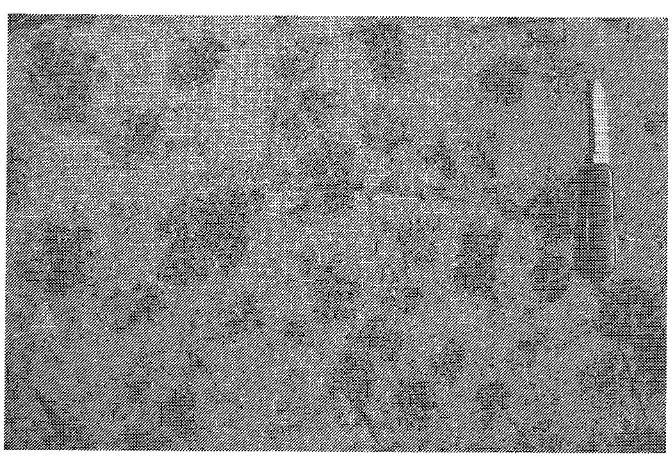


Figure 24 Spotted or mottled peridotite between BD and UM chromitite groups. Light coloured areas are olivine cumulate; black areas are pyroxene oikocrysts which poikiliticly enclose cumulus olivine. Knife (16 cm long) points to stratigraphic top. GSC 204887-T.

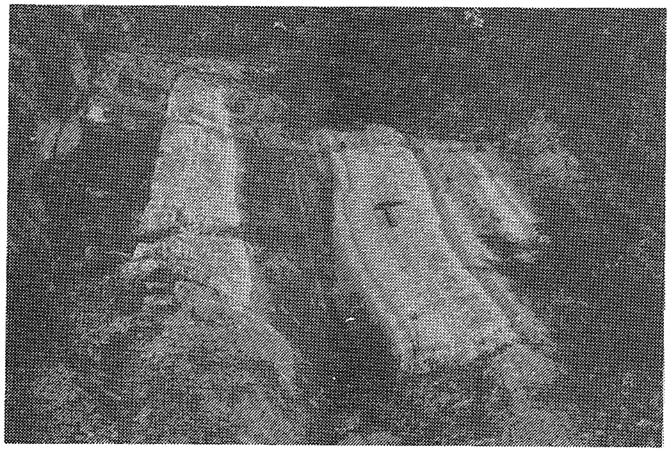
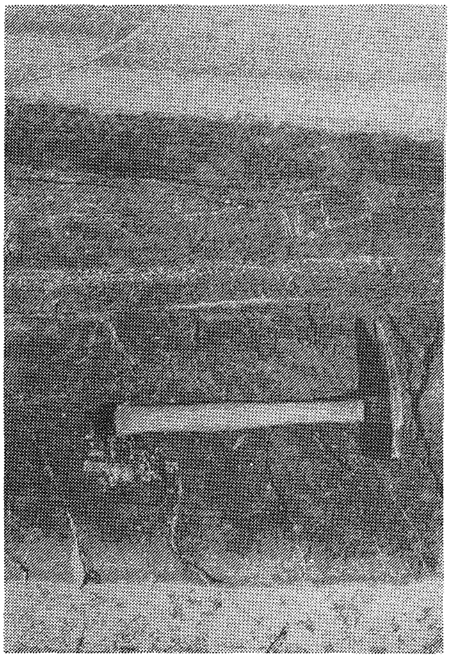


Figure 26 Typical Upper Main Group, Chromitiferous Zone. Pick of hammer head (17cm) points to stratigraphic top. GSC 204887-F.



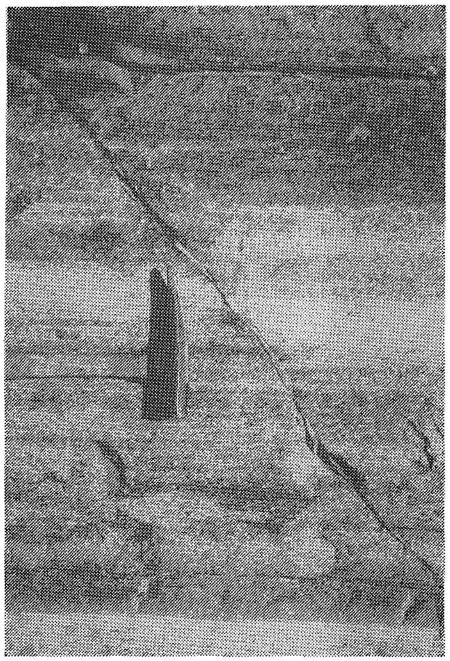


Figure 27 (left) Typical UMmdn chromitite, Chromitiferous Zone. Pick of hammer head (17cm) points to stratigraphic top. GSC 204887-G.

Figure 28 (right) Typical UMudf chromitite, Chromitiferous Zone. Pick of hammer head (17cm) points to stratigraphic top. GSC 204887-H.

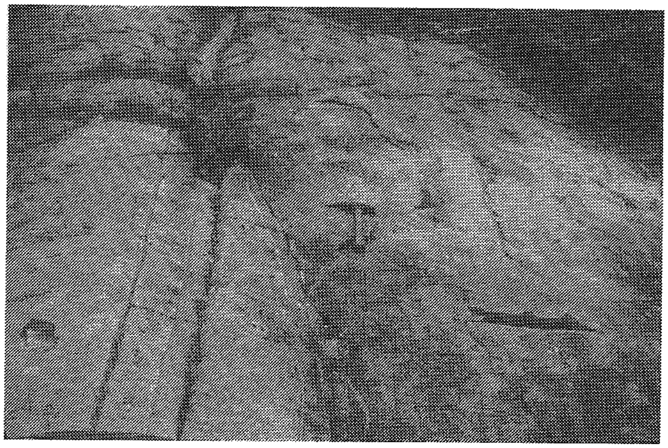
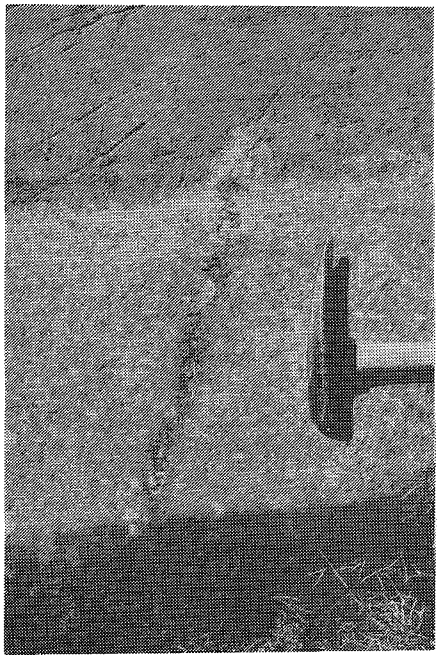
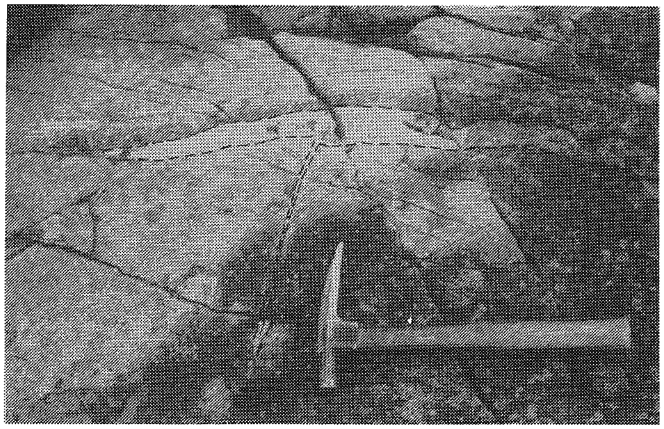


Figure 30 (above) Typical Upper Paired Group, Chromitiferous Zone. Pick of hammer head (17cm) points to stratigraphic top. GSC 204887-V.

Figure 31 (below left) Late magmatic vein cutting knobby peridotite , Layered Zone. Straight, parallel lines in chloritites are glacial striae. Pick of hammer head (17cm) points to stratigraphic top. GSC 204917-A.

Figure 32 (below right) Ponding structure (outlined by dashed line) underlying Lltn. Late magmatic fluids are interpreted to have risen along a fracture (immediate left of hammer head) until trapped by an impermeable chromitite layer. Darkened area (photo right) is due to weathering and lichen cover; lighter area (photo left) is recently stripped outcrop. Pick of hammer head (17cm) points to stratigraphic top. GSC 205036.





The pairs are separated by 60 to 96 cm (average 70 cm) of peridotite. All chromitite layers are dense chromitite, with sharp contacts, and are very consistent along strike. The diagnostic features of the Upper Paired Group are the thickness of the paired chromitites and the stratigraphic intervals between them.

Several features occur within the Chromitiferous Zone which are significant in interpreting the crystallization history of the Sill. These include evidence of late magmatic fluid migration, synmagmatic faulting and synmagmatic soft sediment-like deformation structures.

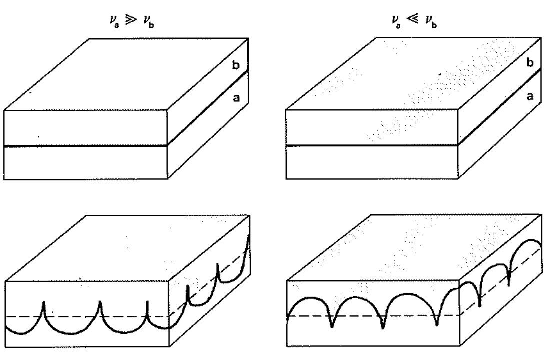
Evidence of late magmatic fluid migration is the occurrence of crosscutting veins of ultramafic material and the presence of "ponding" structures. Figure 31 shows a vein from the Layered Zone (Sheet 5, 140W/67N) which consists of coarse grained pyroxene and which cuts layered peridotite and chloritite. The vein begins at the top of a massive chlorite layer, suggesting that the peridotite was a competent material which fractured and then was invaded by late magmatic fluid originating from the chlorite layer. Ponding structures are interpreted to form when upward migrating magmatic fluids become trapped under impermeable capping layers (usually chromitites). An example is shown in figure 32. Ponding structures are seen at several locations within the Chromitiferous Zone, both along strike and through the stratigraphy: underlying Lltn (Sheet 5, 105W/20N), underlying Dudn (Sheet 275W/77N) and underlying BDbd (Sheet 2, 39W/3S and 35E/27N).

Synmagmatic faulting can be seen at several locations. One example of this is shown in figure 33, where the BDb member is sharply truncated by a synmagmatic fault (Sheet 1, 204W/42N). Of note is the abrupt termination of a cumulus chromite + olivine layer against cumulus olivine with no visible trace of faulting. This feature could be explained as a fault which formed prior to consolidation of the olivine cumulate, as an intrusive breccia, or as due to collapse of a competent chromitite layer during liquifaction of underlying olivine crystal mush (cf. Anketell et al., (1970), Fig. 16). Regardless of the exact mechanism, the feature must have developed prior to complete consolidation of the rock; ie, at a synmagmatic stage. In contrast, note the tectonic offset of the thicker capping chromitite layer (photo upper right); fracture filling is clearly visible.

Soft sediment-like deformation takes three main forms: load casts, drop and sag structures, and slumping .

"Load casts" were noted in several of the chromitite layers, including LMldn and Dldl. Anketell et al.. (1970) suggest (based on modelling studies) that load casts develop as a result of a difference in kinematic viscosity across

Figure 33 Faulting of BDb. The curved surface truncating the chromitite layers without any suggestion of a fault trace or intrusive margin is interpreted to be a synmagmatic break. The lighter coloured olivine cumulates which lie above, below, and along strike of the chromitite layer are continuous and undistinguishable from each other and from fine grained peridotites elsewhere in the intrusion. The offset of the thick uppermost chromitite layer along a fracture with fracture filling is interpreted to be post-magmatic. Pick of hammer head (17cm) points to stratigraphic top. GSC 204958-E-2.



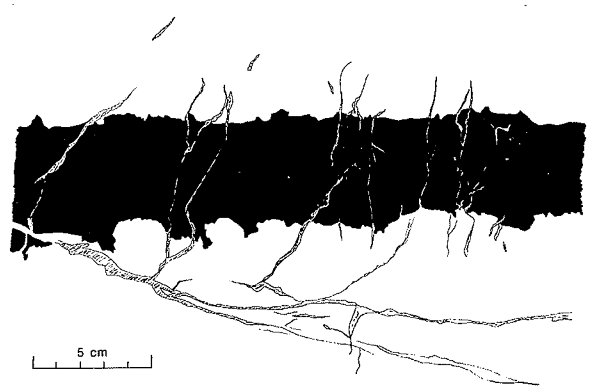


Figure 34a (left) Experimentally developed load casts. Upper blocks show initial configuration and lower blocks final configuration of an experimental system with layer "a" denser than layer "b". Layer "a" was more viscous than layer "b" in the experiment depicted on the left, whereas the reverse was the case in the experiment depicted on the right. In both cases, cusps project into the less viscous layer. Adapted from figure 1 of Anketell et al. (1970).

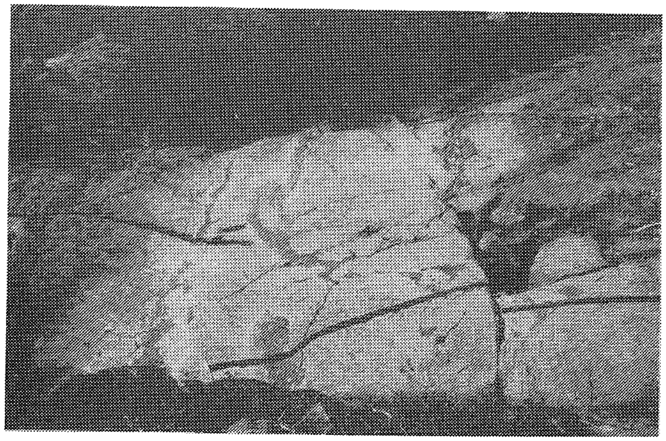
Figure 34b (right) "Load casts" developed in LM1d. Cusps of chromite (black) projecting into peridotite (white) suggest that chromitite was more viscous than the enclosing peridotite. Traced from a photograph. Top of drawing is stratigraphic top.

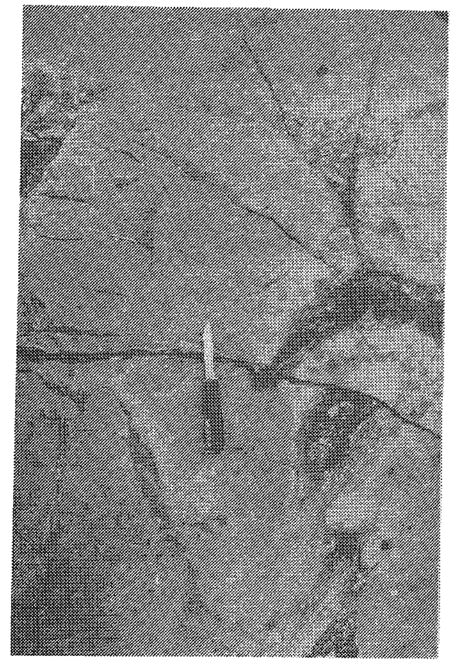
layer boundaries, with the cusps or "flames" pointing into the lower viscosity layer (Fig. 34a). In the case of the Bird River Sill chromitites, cusps of chromitite point into the surrounding peridotite (Fig. 34b), indicating that the peridotite was more fluid than the chromitite. A possible interpretation is that the peridotite became fluidized (ie, less viscous) while still an unconsolidated cumulus pile, thus giving rise to the "load casts".

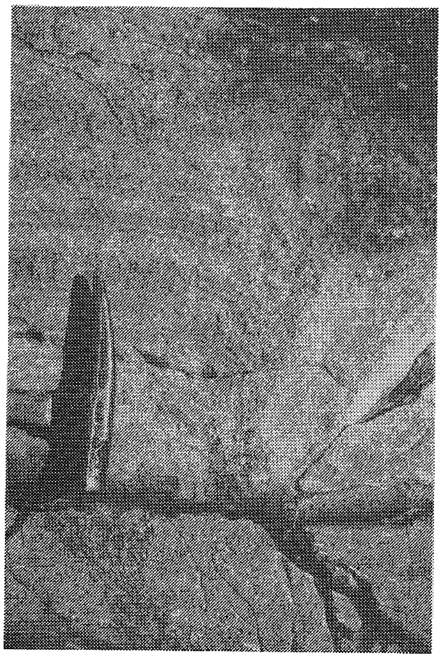
"Drop and sag" structures occur most prominently in the Disrupted Group (Dd). Similar structures in sedimentary rocks of the Torridonian of Scotland (Stewart, 1963) are developed by thin heavy mineral bands in quartzofelspathic clastic sediments. Modelling experiments by Bogacz et al.. (1968) and Anketell et al., (1970) suggest that drop and sag (or crumpled layer) structures arise as a result of gravitationally unstable layering; ie, a more dense layer overlying a less dense layer. The layers will tend to invert to the more stable reversed configuration when activated by some trigger mechanism. These can include seismic shock, stratigraphic loading, or liquefaction. In the case of the Disrupted Group chromitites, the accumulation of denser chromite overlying lighter cumulus olivine creates the gravitationally metastable sequence which, when triggered prior to complete crystallization, will develop these structures.

Slump structures were observed at three locations on the Chrome property: in the banded interval of the Banded & Diffuse Group (Sheet 1, 202E/44N and 195E/48N), in Dld2 (Sheet, 3 160W/83N) and Dudn (Sheet 4, 289W/76N). Figure 35 illustrates the plastic nature of deformation of the chromitite layer, presumably the result of a gravity induced synmagmatic event. Figure 36 portrays a similar example where a layer (BDb) has slumped in a plastic fashion. The effects of tensional strain on a plastic chromitite layer are seen in figure 37 where necking of a dense chromitite layer (BDbd) occurs.

Numerous attitude measurements were made on the chromitite layers. Near the west pit of the 1:200 detail map there is a suggestion of a change of dip progressing up section from 45-60^{o} N in the Lower Group chromitites steepening progressively to 85-90^{o} S in the Upper Paired Group. Further to the east this progressive change up section is not seen; dips change in a random manner both across section and along strike. Although it is tempting to interpret the western data as representing a change in dip of original igneous layering, the complex faulting throughout the property and the lack of supporting data from the remainder of the detail map renders this interpretation uncertain.







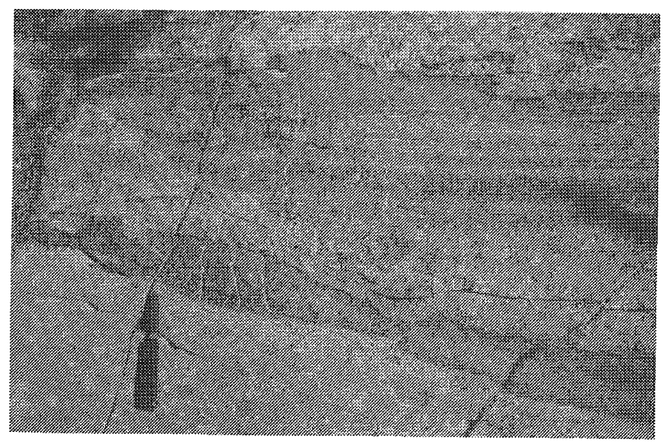


Figure 35a (upper left) Synmagmatic slump of Dld2. The sawcuts crosscutting the layers are approximately 10 cm wide. Stratigraphic top is to the left. GSC 204958-H-2.

Figure 35b (upper right) Detail of the slump, showing synmagmatic plastic flow and disruption of the slumped chromitite layer. Note the absence of slickenside development where the chromitite layer is truncated (upper left). Knife (16 cm long) points to stratigraphic top. GSC 204958-C-1.

Figure 36 (lower left) Plastic deformation of BDb associated with slumping. Pick of hammer head (17cm) points to stratigraphic top. GSC 204958-D-2.

Figure 37 (lower left) Plastic deformation of BDb by tensional strain (necking). The fine white filled fractures crosscutting chromitite layers are interpreted to result from post-magmatic fracturing. Knife (16 cm long) points to stratigraphic top. GSC 204958-F-2.

TRANSITION SERIES (MAP UNIT 2B)

The Transition Series consists of two distinctly different peridotites separated by gabbro and exhibiting original igneous contacts. Strike parallel faults are present, and stratigraphic repetitions occur, but field evidence supports the existence of three stratigraphic zones, described as follows.

Lower Peridotite Zone (map unit $2B_1$)

The lower peridotite grades over a few metres from the patchy peridotite which overlies the Upper Paired chromitites into a knobby weathering peridotite. Due to incomplete exposure of the zone, the thickness can only be estimated (3 to 7 m), but appears to average about 6 m. It is rusty orange weathering, with very fine grained cumulus olivine and up to 50% dark green pyroxene oikocrysts (1 to 2 cm) as resistant weathering knobs. Figure 38 shows a typical outcrop surface. The upper contact with the Gabbro Zone is gradational from orange weathering peridotite to greyish-white weathering gabbro. Knobby pyroxene oikocrysts (1 to 2 cm) persist across the gradational contact, and the transition is defined essentially by the proportion of orange or white in the weathering colour. Rock intermediate between the two distinct end members, or with a mottling of white on orange (or orange within white) has been designated "troctolite", the suggestion being that the mix of colour reflects a mix of original olivine and plagioclase in the original rock. This is similar to the peridotite-gabbro transition between the Layered subzone and Gabbro subzone of the Layered Zone.

The gradational nature of both the lower and upper contacts of this zone creates problems in defining its extent. The lower contact has been placed at the change from patchy pyroxene in the Chromitiferous Zone to knobby pyroxene in the Transition Series. The upper contact is taken to be the change from a predominantly orange weathering colour of the lower peridotite to the mainly white weathering color of the overlying gabbro. These criteria are easily applied in the field.

Gabbro Zone (map unit $2B_2$)

The gabbro is a medium grained rock with plagioclase and pyroxene in about equal proportions. The plagioclase weathers greyish white with dark green pyroxene flecked through the rock. Within the gabbro proper, several variants have been described based on the nature of the pyroxene present. These include knobby gabbro (with cm size knobby oikocrysts), spotted gabbro (with patchy oikocrysts of 5 to 8 cm) and massive gabbro (where the pyroxene is evenly distributed, rather than defining distinct oikocrysts). This upward succession was found at one location, but whether or not this is consistent along strike is uncertain due to limited exposure. Thickness of the unit is about 8 m.

Upper Peridotite Zone (map unit $2B_3$)

The contact of the gabbro with the upper peridotite is abrupt, and is marked by the presence of a coarse grained massive pyroxenite layer up to 20 cm thick and an abundance of egg structures (2 to 14 cm), both mafic and felsic in composition. Although layer-parallel faults are present near the contact, they overlie a distinctly unfaulted igneous contact by about 20 cm. Figure 39 shows an example of the contact, and figure 40 a detail of the pyroxenite layer with egg structures.

The upper peridotite is an orange weathering fine grained olivine cumulate rock with a knobby weathered surface due to resistant pyroxene oikocrysts. It has several features that distinguish it from the lower peridotite (see Fig. 41):

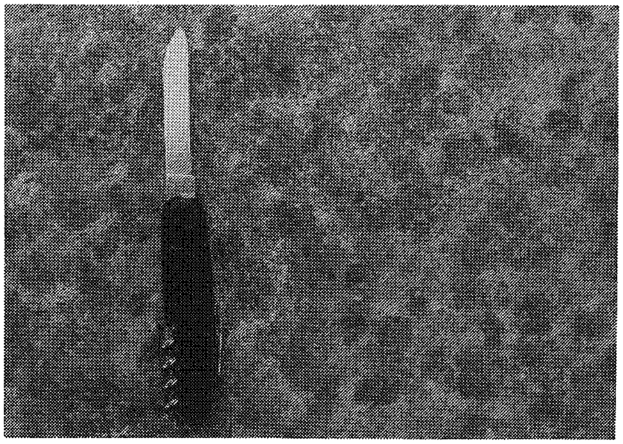
- Whitish fracture-filling. The upper peridotite is cut by numerous random fractures (mm to cm thick) filled with a hard, slickensided, fibrous, white weathering material. The mineralogy of the fracture filling has not yet been determined.

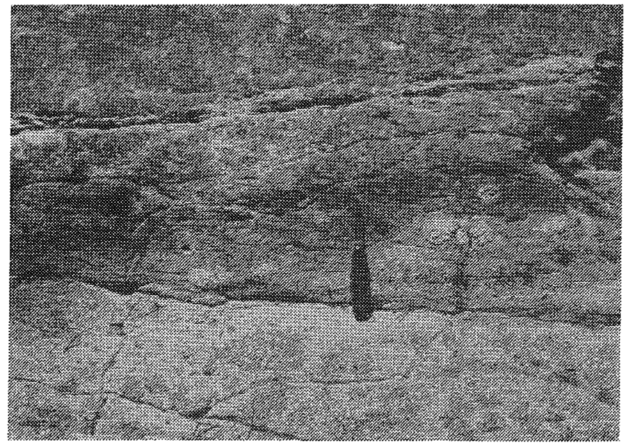
- The presence of egg structures throughout the peridotite. These eggs are similar to those found in the Ultramafic Series Layered Zone; round to elliptical, turquoise coloured, hackly textured, talcose massive chlorite. Eggs of hard, white weathering massive prehnite occur rarely here, as in the Ultramafic Series. Although eggs are concentrated at the gabbro-upper peridotite contact and are largest there, eggs of massive chlorite (1 to 5 cm) are commonly found through the entire thickness and along the full strike length examined in this unit.

- Pyroxene cross veining. A few crosscutting veins (1 to 2cm) of massive pyroxene are found in the upper peridotite.

These distinctive features, which are seen throughout the upper peridotite but not in the lower peridotite, coupled with a clearly unfaulted igneous contact at the top of the gabbro provide solid grounds for defining two separate peridotites in the Transition Series, separated by a gabbro. The similarities between the Ultramafic Series Layered Zone and the Transition Series Upper Peridotite Zone (peridotite-gabbro transition, presence of egg structures and crosscutting pyroxene veins) suggest similar origins.

The upper contact with the Mafic Series rocks is not exposed but the zone's thickness is estimated as 6 to 12 m





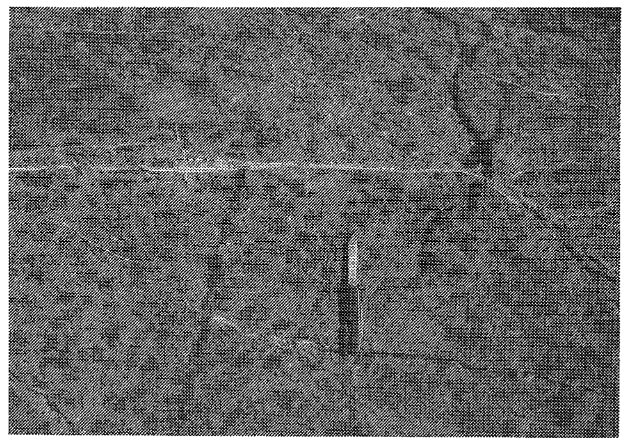


Figure 38 (upper left) Lower Peridotite Zone, Transition Series. Pyroxenes form a knobby weathering surface. Knife (16 cm long) points to stratigraphic top. GSC 204887-J.

Figure 39 (upper right) Contact (under knife handle) of Gabbro Zone and Upper Peridotite Zone, Transition Series. Eggs occur in a massive pyroxenite layer immediately above the contact. A fault intersects the contact at an acute angle. Knife (16 cm long) points to stratigraphic top. GSC 204896-A.

Figure 40 (lower left) Detail of the egg bearing pyroxene layer at the Gabbro - Upper Peridotite contact. Gabbro Zone is visible at the bottom of the photo. Knife (16 cm long) points to stratigraphic top. GSC 204896.

Figure 41 (lower right) Example of the Upper Peridotite Zone, Transition Series. Pyroxene is more patchy than knobby; white (felsic?) veining is common; and eggs (upper left) and pyroxene veins (vertical in photo centre) occur, in contrast of Lower Peridotite Zone (Figure 38). Knife (16 cm long) points to stratigraphic top. GSC 204887-R.

based on the nearest distance to exposed Lower Gabbro Zone rocks.

MAFIC SERIES (MAP UNIT 2C)

Preliminary examination of the Mafic Series rocks showed little of economic interest. As a result, the mapping was conducted at a less detailed scale than was the case in the Mafic and Transition Series. The series has been subdivided into five zones (in upward stratigraphic succession): Lower Gabbro, Xenolith, Quartz Gabbro/Diorite, Trondhjemite and Upper Gabbro Zones.

Lower Gabbro Zone (map unit $2C_1$)

The Lower Gabbro Zone consists of medium grained to pegmatitic gabbro, ranging in composition from anorthositic gabbro to pyroxene rich varieties. Plagioclase is grey in fresh surfaces and "dirty white" on weathered surfaces, whereas pyroxene displays differing shades of dark green. Locally, the pyroxene develops a rusty weathering. Figure 42 shows a typical exposure.

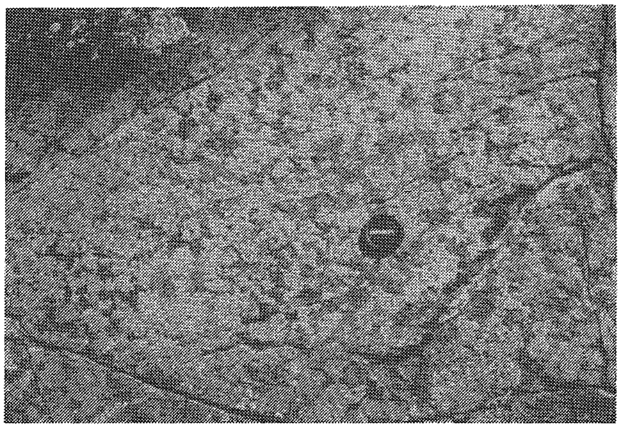
The lower contact with the Transition Series is not exposed on the Chrome property. The upper contact with the overlying Xenolith Zone is gradational and poorly defined.

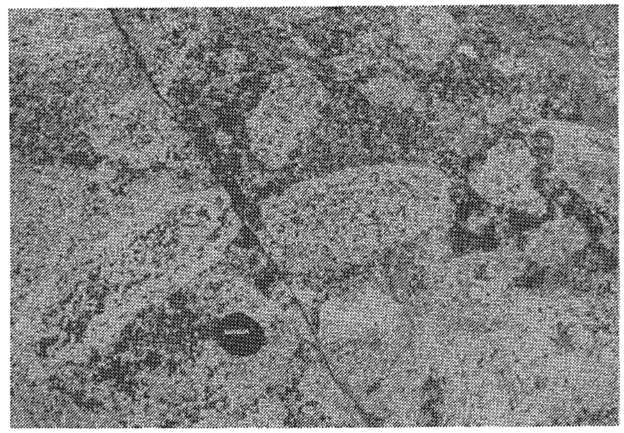
The Lower Gabbro Zone contains the only oxide layer observed in 450 m of Mafic Series stratigraphy, and this layer has been encountered in only one outcrop. It consists of a 1 cm thick layer of dense chromitite that is semi-continuous for at least 3 metres, and is contorted, broken in places and folded.

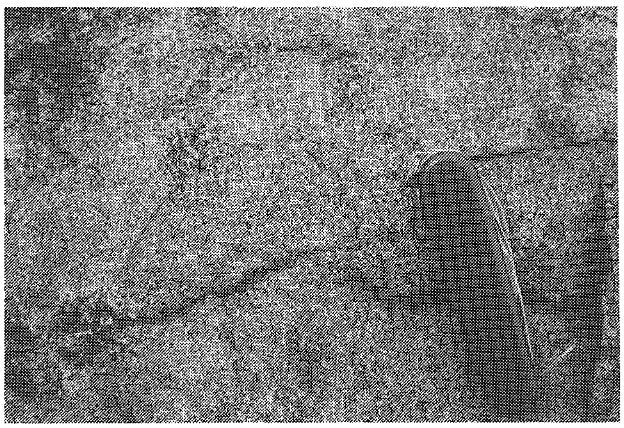
Xenolith Zone (map unit $2C_2$)

The Xenolith Zone consists of medium- to coarse-grained gabbro similar in appearance to that of the Lower Gabbro Zone, but is distinguished by the presence of numerous gabbroic to anorthositic blocks or inclusions. Block margins are commonly marked by a rind having a plagioclase/pyroxene proportion that is different from that of the block: thus anorthositic gabbro blocks have pyroxene rich rinds, and more mafic gabbro blocks have plagioclase rich rinds. Plagioclase rich rinds are by far the most common. Size of blocks generally ranges from 20 cm to 50 cm, but some are up to about 1 metre. Figure 43 shows a typical exposure.

The lower contact with the underlying Lower Gabbro Zone is gradational. The upper contact with the overlying Quartz Gabbro - Diorite Zone is better defined due to the distinctiveness of the two rock types.







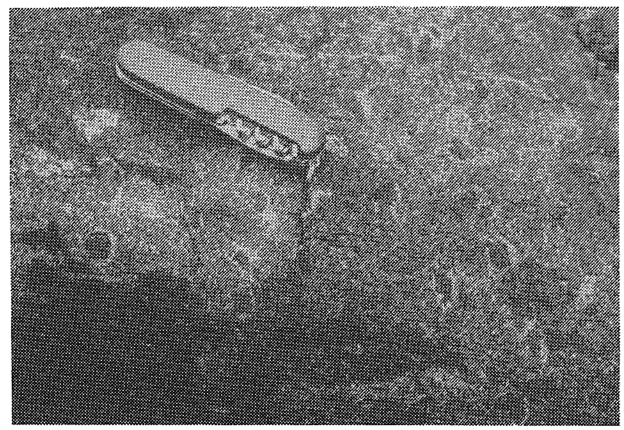


Figure 42 (upper left) Normal gabbro of the Lower Gabbro Zone, Mafic Series. Lens cap is about 6 cm diameter. GSC 204887-K.

Figure 43 (upper right) Anorthositic gabbro xenoliths in mafic gabbro, Xenolith Zone, Mafic Series. Lens cap is about 6 cm diameter. GSC 204887-U.

Figure 44 (lower left) "Chicken track" gabbro of the Quartz Gabbro - Diorite Zone, Mafic Series. Knife is 9 cm long. GSC 204917-B.

Figure 45 (lower right) Porphyritic diorite with "eyebrow" texture, Quartz Gabbro - Diorite Zone, Mafic Series. Knife is 9 cm long.

The origin of the Xenolith Zone is problematic. It could represent an autobreccia (ie, part of the Lower Gabbro Zone, broken up in place as a result of a later magma intrusion or synmagmatic seismic activity). Alternatively it could have originated by stoping of blocks from the roof of the intrusion (ie, part of the Upper Gabbro Zone). The question has not been resolved through the present field studies.

Quartz Gabbro - Diorite Zone (map unit $2C_3$)

The Quartz Gabbro - Diorite Zone is distinctly different from the anorthositic gabbros that comprise the bulk of the Mafic Series. It consists of three rock types, which form a stratigraphic succession within the zone: "chicken track" gabbro, porphyritic diorite and massive diorite. A few aplitic mafic dykes intrude these rocks.

The bulk of the zone consists of massive diorite, a fine grained equigranular rock, which is dark grey on the fresh surface, and weathers to white plagioclase (60 - 70%) and dark green to black pyroxene(30 - 40%). Centimetre sized pods of plagioclase and quartz are present in some areas.

"Chicken track" gabbro occurs at the base of the zone, and consists of fine to coarse grained plagioclase phyric gabbro in which lath-like, randomly oriented cumulus plagioclase look like chicken tracks. Outlining of plagioclase by dark intercumulus pyroxene accentuates the pattern. Figure 44 shows an example of the finer grained variety.

Porphyritic gabbro overlies the chicken track gabbro and is characterized by pyroxene phenocrysts 0.5 to 2 cm diameter in a finer grained matrix. The contact is gradational over a few centimetres, from chicken track gabbro with no phenocrysts to chicken track gabbro containing up to 30% fine pyroxene phenocrysts. Stratigraphically higher, the rock is a more massive diorite with pyroxene phenocrysts of 1 to 2 cm. Around each phenocryst, a rim of plagioclase a few millimeters thick is developed, so that the phenocryst and rim resemble an eye and eyebrow (Fig. 45). Porphyritic diorite can also include layers of massive diorite in places. The contact with the overlying Trondhjemite Zone is gradational over a few metres.

Trondhjemite Zone (map unit $2C_4$)

The Trondhjemite Zone consists of medium grained dioritic rock. The fresh surface is grey to mottled light and dark; the weathered surface appears milky to pale pinkish white with black hornblende laths (20 to 40%). Aplitic dykes occur here as in the underlying zone. The contact with the Upper Gabbro Zone is commonly faulted, comprising a shear zone a few metres wide containing discontinuous milky quartz veins.

The Tronjhemite Zone is equivalent to the interval described by Dmytriw (1984) as "variable diorite granophyre", containing 7 to 45% modal quartz, 15 to 40% plagioclase (composition An_{10-45}) and essentially no alkali feldspar. The name trondhjemite is used here, although with the amount of hornblende it might be considered as tonalite or diorite.

Upper Gabbro Zone (map unit $2C_5$)

The Upper Gabbro Zone is similar in appearance to the Lower Gabbro Zone, consisting of massive, medium grained gabbro to anorthositic gabbro. In contrast to the Lower Gabbro Zone the pegmatitic variety is rarer here, and the composition tends to be less mafic.

BERNIC LAKE FORMATION (MAP UNIT 3)

As with unit 1, the Bernic Lake Formation was not mapped in this study except to delineate the upper margin of the BRS. The description which follows is summarized from Trueman (1980).

The Bernic Lake Formation is dominated by clastic sedimentary rocks, interlayered with diverse volcanic and derivative volcaniclastic rocks and iron formation. Rock types documented by Trueman include basalt, andesite, dacite, rhyolite, volcanic wackes, iron formation and, most abundantly, conglomerate. Deposition of the conglomerate appears to have been as debris flows. The presence of clasts of Bird River Sill gabbros in the conglomerate implies that the Sill was unroofed and was unconformably overlain by the Bernic Lake Formation (Trueman, 1980).

In the map area, only a few outcrops of this unit were seen, immediately south of Peterson Creek. The rocks observed were dark greyish green, chloritic volcanic wacke overlain by conglomerate. The conglomerate included angular boulders of gabbroic rock up to 20 cm in size, set in a fine grained chloritic matrix. The contact between the Bernic Lake Formation and the underlying Bird River Sill lies in the valley occupied by Peterson Creek, and is not exposed.

MAFIC DYKE (MAP UNIT 4)

A fine grained mafic dyke cuts the Lower Gabbro, Xenolith and Quartz Gabbro - Diorite Zones in the southwest corner of the map. It appears black on the fresh surface and weathers to greyish buff. It may be a feeder dyke to volcanic rocks which overlie the Sill.

SUMMARY OF SALIENT POINTS ARISING FROM FIELD MAPPING

The current mapping program has brought to light several important features which were not previously recognized.

Previous workers as far back as Brownell and Bateman have recognized the fundamentally layered nature of the Sill. Trueman (1970) and Scoates (1983) both presented stratigraphic subdivisions, and Trueman's map shows the layering on a broad scale. The maps presented here demonstrate the fine degree of stratigraphic subdivision that was recognized, and the impressive strike continuity of even millimetre scale stratigraphic features which occur. The preliminary stratigraphy presented by Scoates (1983) has been validated and somewhat amplified. The identification of marker horizons for the Chromitiferous Zone will be of value for locating and following stratabound or stratiform mineralization contained in the zone.

The effect of faulting has also been recognized since the earliest work; the current mapping demonstrates in detail its significance in following marker or ore horizons. Offset of layers, loss of layer continuity, and repetition of layers by faults will be significant in the exploitation of any mineralization. The structural study in progress by W.C. Brisbin (University of Manitoba) may provide further information on faulting.

Numerous observations within the Ultramafic Series aid in interpreting the crystallization history of the Sill. Trueman (1970) appeals to crystal settling and magmatic current activity. The nature of chromitite as continuous layers suggests that magmatic currents were absent, or had minimal effect after initial deposition of crystals. The abundance of "load casts", "drop and sag", and slumping and necking of layers suggests that a process analogous to soft sediment deformation was an important synmagmatic process which operated on the magmatic sediments (cumulus minerals) of the Sill between initial deposition and final crystallization. Fluidization of these magmatic "sediments" (by migration of intercumulus fluids or injection of new magma) can be appealed to as a mechanism for explaining some of these features, and is supported by the recognition of fluid migration features (cross veining and ponding structures).

The recognition of three peridotite to gabbro cycles (Fig. 46) is inconsistent with previous interpretations on the origin of the Sill. Scoates (1983) cites the absence of repetitive cycles involving the disappearance and reappearance of cumulus phases, and suggests an origin from a single magmatic pulse which differentiated in place. The

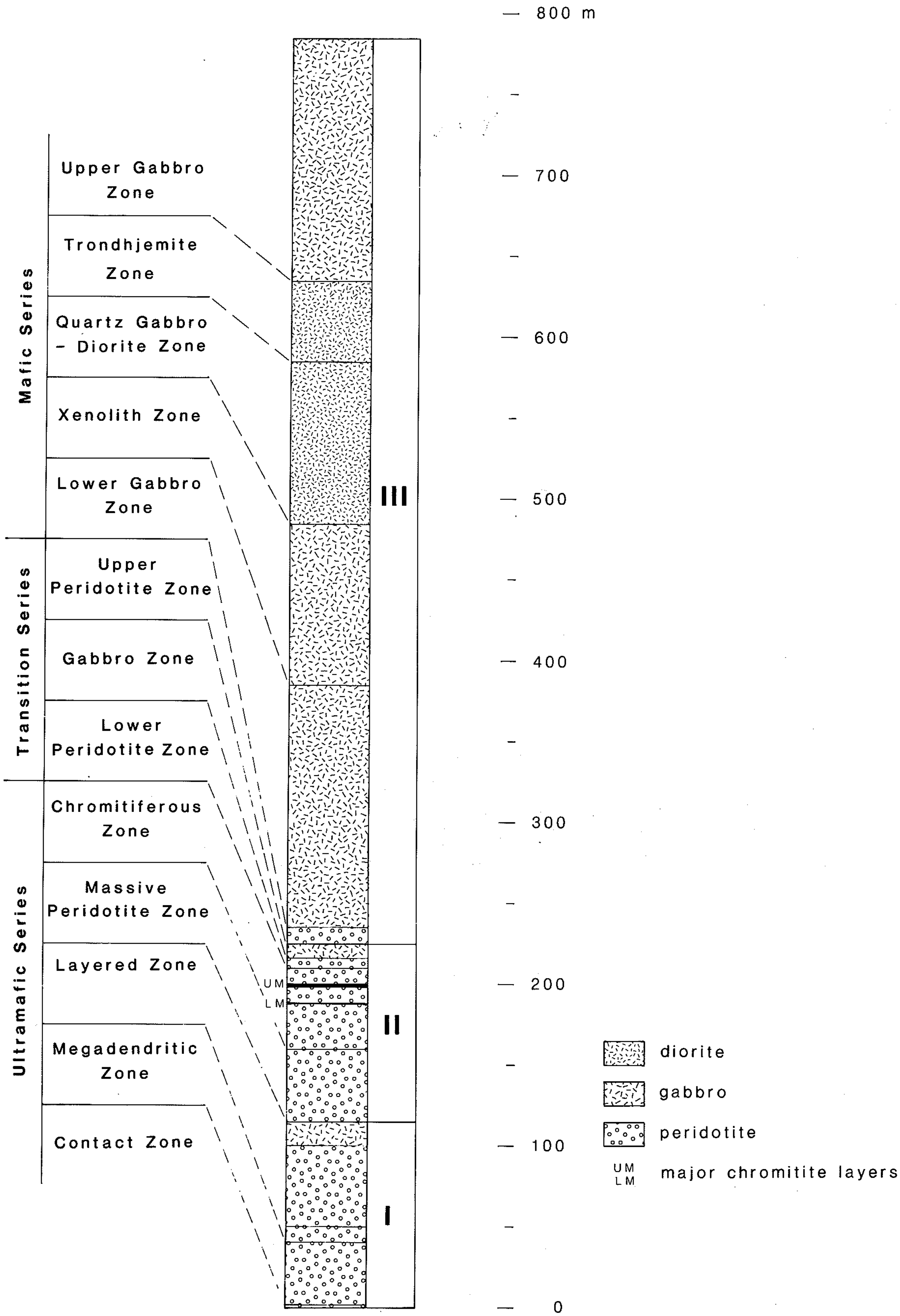


Figure 46 Correlation of stratigraphic subdivisions (left) with stratigraphic column and magmatic cycles (right). Magmatic cycles (Roman numerals) are defined by igneous peridotite to gabbro sequences.

recognition in this study of three peridotite to gabbro transitions (in the Ultramafic Series Layered Zone, in the Transition Series, and between the Transition and Mafic Series) suggests multiple magmatic events of some kind, perhaps new pulses of magma, or repeated convective turnover within the chamber. It is interesting that the additional observation of dendritic crystal growth correlates with the lowermost portions of each of the two lower cycles.

A feature of interest is the occurrence of egg structures near the peridotite-gabbro transitions. Eggs occur rarely in the Massive Peridotite Zone and in the Chromitiferous Zone, far from gabbros, but the two main occurrences are close to gabbro. One of these is in the Ultramafic Series Layered Zone (in peridotite underlying the Gabbro subzone) and the other is in the Transition Series Upper Peridotite Zone (in peridotite overlying the Gabbro Zone). Their common occurrence close to igneous cycle transitions is probably related to their mode of genesis.

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Captions to accompany chromitite sections
(Fig. 8, 10, 16, 19, 25, 29)
in map pocket

Figure 8 Selected stratigraphic columns through the Lower Group chromitites, Chromitiferous Zone. White represents peridotite, black represents dense chromitite, white speckles represent silicate inclusions. Datum is arbitrarily selected at the top of Lutk.

Figure 10 Selected stratigraphic columns through the Disrupted Group chromitites, Chromitiferous Zone. White represents peridotite, black represents dense chromitite, white speckles represent silicate inclusions. Datum is arbitrarily selected at the top of Dudn.

Figure 16 Selected stratigraphic columns through Lower Main Group chromitites. White represents peridotite, h indicates harrisitic peridotite, black represents dense chromitite, stipling represents diffuse chromitite. Datum is arbitrarily selected at the top of LMlm.

Figure 19 Selected stratigraphic columns through Banded & Diffuse Group chromitites. White represents peridotite, black represents dense chromitite, stipling represents diffuse chromitite. Datum is arbitrarily selected at the base of BDbd.

Figure 25 Selected stratigraphic columns through Upper Main Group chromitites. White represents peridotite, black represents dense chromitite, stipling represents diffuse chromitite. Datum is arbitrarily selected at the top of UMudn.

Figure 29 Selected stratigraphic columns through Upper Paired Group chromitites. White represents peridotite, black represents dense chromitite. Datum is arbitrarily selected at the top of UPu2.