100% Resolution Test Chart

9

National Library
of CanadaBibliothèque nationale
du CanadaCANADIAN THESES
ON MICROFICHETHÈSES CANADIENNES
SUR MICROFICHENAME OF AUTHOR/NOM DE L'AUTEUR Gregory R. DunningTITLE OF THESIS/TITRE DE LA THÈSE The Geology and Platinum-group Mineralization of the Roby
Zone, Lac des Iles Complex, Northwestern Ontario.UNIVERSITY/UNIVERSITÉ Carleton UniversityDEGREE FOR WHICH THESIS WAS PRESENTED/
GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE M.Sc.YEAR THIS DEGREE CONFERRED/ANNÉE D'OBTENTION DE CE DEGRÉ 1979NAME OF SUPERVISOR/NOM DU DIRECTEUR DE THÈSE Dr. David Watkinson

Permission is hereby granted to the NATIONAL LIBRARY OF
CANADA to microfilm this thesis and to lend or sell copies
of the film.

*L'autorisation est, par la présente, accordée à la BIBLIOTHÈ-
QUE NATIONALE DU CANADA de microfilmer cette thèse et
de prêter ou de vendre des exemplaires du film.*

The author reserves other publication rights, and neither the
thesis nor extensive extracts from it may be printed or other-
wise reproduced without the author's written permission.

*L'auteur se réserve les autres droits de publication; ni la
thèse ni de longs extraits de celle-ci ne doivent être imprimés
ou autrement reproduits sans l'autorisation écrite de l'auteur.*

DATED/DATE March 1, 1979 SIGNED/SIGNÉ Greg DunningPERMANENT ADDRESS/RÉSIDENCE FIXE 122 Rutherford CourtKanata, Ontario, K2K 1N5

National Library of Canada

Cataloguing Branch
Canadian Theses Division

Ottawa, Canada
K1A 0N4

Bibliothèque nationale du Canada

Direction du catalogage
Division des thèses canadiennes

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us a poor photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

**THIS DISSERTATION
HAS BEEN MICROFILMED
EXACTLY AS RECEIVED**

AVIS

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de mauvaise qualité.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

**LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE**

THE GEOLOGY AND PLATINUM-GROUP MINERALIZATION OF THE
ROBY ZONE, LAC DES ILES COMPLEX,
NORTHWESTERN ONTARIO.

BY

GREGORY R. DUNNING, B.Sc.

A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfilment of the requirements
for the degree of Master of Science.

Department of Geology
Carleton University
Ottawa, Ontario
February, 1979

© 1979 Gregory R. Dunning

The undersigned hereby recommend to the Faculty
of Graduate Studies and Research acceptance of
this thesis, submitted by Greg Dunning, B.Sc.,
in partial fulfilment of the requirements for
the degree of Master of Science.

.....*G.B. Steppan*.....

Chairman, Department of Geology

.....*David H. Wash*.....

Thesis Supervisor

Carleton University

Ottawa, Ontario

February 26, 1979.

ABSTRACT

The Lac des Iles complex is one of several mafic-ultramafic complexes north of Thunder Bay, Ont. It is composed of three intrusions, the western gabbro, eastern gabbro and ultramafic body (in order of emplacement).

The western gabbro, which contains the Roby zone, is coarse-grained to pegmatitic and consists of gabbro (70%), norite (20%), clinopyroxenite (10%) and anorthosite (minor). All rocks are crystal cumulates, the cumulus minerals occurring with increasing stratigraphic height are plagioclase, orthopyroxene-plagioclase and clinopyroxene. Mineral-graded, size-graded, chemical-graded and isomodal layers are present and are steeply dipping. Norite is generally fresh while gabbro and clinopyroxenite are moderately to strongly altered to amphibole-chlorite-epidote assemblages. Some recrystallization of amphibole and epidote has occurred.

Coexisting bronzite and augite from noritic rocks of the western gabbro give equilibration temperatures ranging from 1066°C to 726°C. Those for the eastern gabbro are approximately 950°C and those from the ultramafic body average 1100°C for peridotite and 1030°C for pyroxenite.

Primary, secondary and metamorphic sulfide assemblages are present in the Roby zone which generally correspond to the silicate assemblages. The primary assemblage pyrrhotite-pentlandite-pyrite-chalcopyrite

predominates in fresh noritic rocks. Mobilization of Cu, Fe and S has resulted in the formation of pyrite- and chalcopyrite-rich assemblages in altered gabbroic rocks. Subsequent metamorphism has given rise to the assemblages pentlandite-violarite and pentlandite-violarite-millerite in Ni-rich sulfide blebs.

Platinum-group sulfides, antimonides and tellurides occur with primary, secondary and metamorphic sulfide assemblages. Vysotskite (Pd,Ni)S, and kotulskite Pd(Te,Bi) are the most abundant PGM in the Roby zone. Braggite (Pt,Pd)S, stibiopalladinite $\text{Pd}_{5+x}\text{Sb}_{2-x}$ and unnamed $\text{Ag}_4\text{Pd}_3\text{Te}_4$ are first identified from Lac des Iles in this study.

The eastern gabbro is Fe-rich but barren of Cu, Ni and PGE and is not co-magmatic with the western gabbro.

The magma for the western gabbro had high initial concentrations of Cu, Ni, PGE, S and H_2O . Late-stage pyroxene cumulates were accompanied by Cu-Ni-Fe sulfide droplets which further concentrated PGE.

TABLE OF CONTENTS

ABSTRACT	1
TABLE OF CONTENTS	111
LIST OF FIGURES	v
LIST OF TABLES	vi11
LIST OF APPENDICES	viii1
CHAPTER 1 INTRODUCTION	1
LOCATION OF STUDY AREA	1
PURPOSE OF STUDY	1
METHOD OF STUDY	3
CHAPTER 2 REGIONAL GEOLOGY	5
INTRODUCTION	5
MAFIC-ULTRAMAFIC INTRUSIONS	5
GRANITIC ROCKS	10
DIABASE	11
PLEISTOCENE AND RECENT DEPOSITS	12
STRUCTURAL GEOLOGY	12
CHAPTER 3 GEOLOGY OF THE LAC DES ILES COMPLEX	14
ULTRAMAFIC INTRUSION	14
WESTERN GABBRO	23
EASTERN GABBRO	27
CHAPTER 4 GEOLOGY OF THE ROBY ZONE	32
INTRODUCTION	32
PETROGRAPHY OF DRILL HOLE P-57	34
LAYERING IN THE ROBY ZONE	50

PYROXENES OF THE WESTERN GABBRO	60
PYROXENE CHEMISTRY	61
PYROXENE THERMOMETRY	65
SUMMARY	70
CHAPTER 5 COPPER-NICKEL-IRON AND PLATINUM-GROUP	
ELEMENT MINERALIZATION	72
INTRODUCTION	72
SULFIDE MINERAL ASSEMBLAGES	73
SUMMARY-HISTORY OF SULFIDES IN THE ROBY ZONE	77
PLATINUM-GROUP MINERALS	80
SUMMARY-OCCURRENCE OF PGM IN THE ROBY ZONE	91
CHAPTER 6 DISCUSSION-HISTORY OF THE WESTERN GABBRO	93
ACKNOWLEDGEMENTS	100
REFERENCES CITED	101
APPENDICES	103

LIST OF FIGURES

1. LOCATION MAP	2
2. ARCHEAN GEOLOGY OF THE LAC DES ILES AREA	7
3. GEOLOGY OF THE LAC DES ILES COMPLEX	15
4. PHOTOMICROGRAPHS OF ULTRAMAFIC ROCKS	17
5. GROUND MAGNETIC SURVEY MAP OF THE EASTERN GABBRO	28
6. LOCATION OF DRILL HOLES IN THE ROBY ZONE	33
7. ROCK TYPES, CU, NI AND PGE VALUES IN DDH P-97	37
8. ROCK TYPES, PYROXENE CHEMISTRY, CUMULUS MINERALS AND CU, NI AND PGE VALUES IN DDH P-57.	38
9. PHOTOMICROGRAPHS OF ROCKS OF WESTERN GABBRO	42
10. GEOLOGICAL SECTION 521	46
11. GRADED LAYERS IN GABBRO	52
12. PHOTOGRAPHS OF LAYERING IN DDH P-48	53
13. GEOLOGICAL SECTION 515	57
14. COMPOSITION OF ORTHOPYROXENE AND PLAGIOCLASE FROM DDH P-57 AND PYROXENE EQUILIBRATION TEMPERATURES	62
15. COMPOSITION OF PYROXENES FROM THE LAC DES ILES COMPLEX	64
16. SULFIDE ASSEMBLAGES PRESENT IN THE ROBY ZONE	74
17. SULFIDE ASSEMBLAGES AND ASSOCIATED PGM FROM THE ROBY ZONE	76
18. PHOTOMICROGRAPHS OF PLATINUM-GROUP MINERALS	84
19. COMPOSITION OF VYSOTSKITE AND BRAGGITE	85

20. PHOTOMICROGRAPHS OF PLATINUM-GROUP MINERALS	87
21. PHOTOMICROGRAPHS OF PLATINUM-GROUP MINERALS	88
22. MINERALIZED ZONES (AFTER PYE, 1968) AND LOCATION OF THE ROBY ZONE	105

LIST OF TABLES

1. TABLE OF FORMATIONS, LAC DES ILES AREA	6
2. COMPARISON OF WESTERN AND EASTERN GABBROS	31
3. CLASSIFICATION OF ROCK TYPES OF THE WESTERN GABBRO	35
4. PYROXENE TEMPERATURES FROM THE WESTERN AND EASTERN GABBROS	67
5. PYROXENE TEMPERATURES FROM THE ULTRAMAFIC BODY AND GABBROIC INCLUSIONS	68
6. OPTICAL PROPERTIES, ANALYSES AND OCCURRENCE OF PLATINUM-GROUP MINERALS	81

LIST OF APPENDICES

A	PREVIOUS WORK	103
B	PROCEDURE FOR SULFIDE CONCENTRATION	108
C	PETROGRAPHY OF DDH P-57	110
D	PETROGRAPHY OF SULFIDE ASSEMBLAGES	113
E	ELECTRON MICROPROBE OPERATING CONDITIONS	117
F	CHEMICAL COMPOSITION OF ORTHOPYROXENE AND CLINO- PYROXENE FROM DDH P-57	118
G	MICROPROBE ANALYSES OF SULFIDES FROM THE ROBY ZONE	122
H	MICROPROBE ANALYSES OF PGM FROM THE ROBY ZONE	126
I	EXPLORATION SUGGESTIONS	128

INTRODUCTION

LOCATION OF STUDY AREA

The Lac des Iles complex is located approximately 80 kilometres north-northeast of Thunder Bay, Ontario with its centre located at approximately $89^{\circ}36'$ west longitude and $49^{\circ}11'$ north latitude (figure 1). Interest in the Lac des Iles complex as a possible host for Cu-Ni sulfide deposits led to several exploration programs being conducted in the 1950's and 1960's. This exploration led to the discovery of several zones of disseminated Cu-Ni sulfides and platinum-group elements (PGE) in the gabbros and norites of the southern part of the complex.

Work done in 1975 and 1976 by Texasgulf Canada Ltd. succeeded in outlining a zone, the Roby zone, approximately 1220 metres long and 270 metres wide, extending to an unknown depth, which contains significant Pd-Pt mineralization in addition to the previously known Cu-Ni sulfides. The thesis area is restricted to this zone. Previous work done in the Lac des Iles area is reported in appendix A.

PURPOSE OF STUDY

This thesis was undertaken to determine the nature of the layering in the Roby zone and the relationship of mineralization to that layering. The study consists of two parts:

1. Petrology of the layered igneous rocks of

Figure 1. Location Map showing outline of Lac des Iles complex.

the Roby zone including a study of the pyroxene chemistry and

2. An investigation of the platinum-group minerals (PGM) and their relationship to Cu-Ni-Fe sulfides and the host rocks.

METHOD OF STUDY

Twenty-five days were spent mapping in the Lac des Iles complex and core from sixteen diamond drill holes was examined to gain familiarity with the rocks of the ore zone. One of these holes (P-57) which contains a wide variety of rock types and high Cu-Ni and PGE values was sampled in detail. Values reported in this study are for total PGE plus gold and were obtained from Texasgulf Canada Ltd.

Thin sections were made from core samples taken over the length of DDH P-57. In addition, polished thin sections were made for the electron microprobe analysis of silicate minerals. Details of the electron microprobe procedures are presented in appendix E.

Polished sections of high assay units of core from many drill holes were examined by reflected light microscope to study the disseminated Cu-Ni sulfides and locate PGM. Due to the sparseness of PGM, heavy minerals from units with high assays were concentrated using a heavy mineral separation technique. Details of this procedure are given in appendix B. The concentrates were made into

monolayer polished sections for study. Selected ore minerals were analysed using the electron microprobe.

REGIONAL GEOLOGY

INTRODUCTION

The Lac des Iles complex is in the Wabigoon volcanic-plutonic belt of the Superior Province (Goodwin, 1977). This belt, which strikes approximately east-northeast, consists of Archean mafic, intermediate and felsic metavolcanics and associated conglomerate, greywacke and iron formation. The metavolcanics and metasediments are intruded by small mafic-ultramafic intrusions and granitic rocks, also of Archean age (figure 2). Sills and dykes of Keweenaw diabase have intruded all the aforementioned lithologies. Only mafic-ultramafic intrusions, granitic rocks and diabase are located near the study area.

MAFIC-ULTRAMAFIC INTRUSIONS

Several mafic intrusions are present in the Lac des Iles area: at Lac des Iles, Legris Lake, Shelby Lake, Wakinoo Lake, and Demars Lake (figure 2). They are the oldest intrusive igneous rocks in the area (Pye, 1968).

The largest ultramafic intrusion in the area occupies the northern portion of the Lac des Iles complex. Metapyroxenite has been reported in association with metadiorite from the intrusion at the south end of Demars Lake.

TABLE 1. Table of Formations in the Lac des Iles
Area, after Pye, 1968.

CENOZOIC

PLEISTOCENE & RECENT

Glacial drift, gravel, sand, silt

Unconformity

PRECAMBRIAN

PROTEROZOIC

KEWEENAWAN

Diabase

Intrusive contact

ARCHEAN

Granitic Rocks

Intrusive contact

Ultramafic Rocks - peridotite, pyroxenite,
websterite

Mafic Rocks - gabbro, norite

Intrusive contact

Metasediments

Metavolcanics

Figure. 2.

Lac des Iles Complex

Terminology based on primary igneous rock type will be used to describe rocks of the Lac des Iles complex (table 3). Alteration and metamorphism have not obscured the primary mineralogy and there has been no pervasive penetrative deformation.

The Lac des Iles complex is the largest body of its type in the area. It has a northern ultramafic intrusion composed of peridotite, pyroxenite and a core of websterite. Detailed drilling indicates that the southern part of the complex contains two distinct intrusions, the western and eastern gabbros. The western gabbro is composed of steeply dipping layers of gabbro, norite, clinopyroxenite and minor anorthosite, and contains disseminated Cu-Ni-Fe sulfides and PGM. The eastern gabbro is composed of gabbro and norite, is oxide-rich, but contains only sparse, disseminated grains of sulfide. The geology of the Lac des Iles complex will be described in further in chapter 3.

Legris Lake

An intrusion of quartz gabbro, roughly 8 kilometres long and 3 kilometres wide occurs along the south shore of Legris Lake and extends to the southwest. The gabbro is massive, medium-grained, generally equigranular and is composed of plagioclase, hornblende, orthopyroxene, clinopyroxene, magnetite, chlorite and

apatite (Kaye, 1969). It differs from the Lac des Iles gabbros in its ubiquitous biotite, quartz and plagioclase of andesine composition (Pye, 1968).

Associated with the gabbro is diorite, a dark green-grey rock composed of hornblende and andesine which is gradational into the gabbro (Kaye, 1969).

The cigar-shaped body immediately to the south of the Legris Lake intrusion is composed of actinolite and chlorite and has been called a feldspathic hornblendite by Kaye (1969).

Shelby Lake

The Shelby Lake intrusion, a long, sinuous body extending south from the Lac des Iles complex, is composed of diorite and serpentized olivine gabbro. Kaye (1969) described the body as being "considerably granitized".

Wakino Lake

The Wakino Lake intrusion is roughly triangular in outline and is composed of diorite and hornblende gabbro very similar to the Legris Lake body (Kaye, 1969). Gabbro, rich in disseminated magnetite is the predominant lithology west of Wakino Lake, whereas the northeastern lobe of the intrusion is composed of medium-to coarse-grained diorite, often granitized (Kaye, 1969).

Demars Lake

The Demars Lake intrusion occurs on the southwest side of the Lake and is composed of diorite, pyroxenite and "ortho-amphibolite" (Kaye, 1969). The rocks are strongly altered with pyroxenite now composed of hornblende and actinolite-tremolite with only relict pyroxene. Plagioclase in the ortho-amphibolite is strongly saussuritized. Both the pyroxenite and ortho-amphibolite contain minor pyrrhotite and pentlandite.

GRANITIC ROCKS

The granitic rocks enclosing the Lac des Iles complex, described by Pye (1968), consist of granite, quartz monzonite, granodiorite and quartz diorite, and he reported gradational changes between these rock types. They contain up to 30 percent of biotite or hornblende and rarely muscovite. Some, near the Lac des Iles complex, contain a minor amount of pyroxene. Most of the granitic rocks are massive but locally they are foliated and have been termed granite gneiss by Pye (1968).

Granitic dykes cut both the Archean metavolcanics and gabbro and peridotite of the Lac des Iles complex. A zone of granite containing large blocks of amphibolite is present adjacent to the west contact of the ultramafic intrusion. The blocks are inter-

puted to be metamorphosed equivalents of the ultramafic engulfed by the granite. All granites in the Lac des Iles area are thought to have been emplaced during the Kenoran orogeny (Pye, 1968).

Kaye (1969) distinguished a granitic gneissic complex to the west of the Shelby Lake intrusion from granitic rocks to the east that he interpreted to be younger. Pye (1968) did not make such a distinction, however, and for the sake of uniformity all granitic rocks have been included in one map unit (figure 2).

DIABASE

Flat-lying sills of Keweenawan diabase are prominent in the Lac des Iles area (Pye, 1968). They constitute the youngest rock formation in the area and their erosional remnants form steep-sided, flat-topped mesas. Associated diabase dykes intrude both the ultramafic and mafic intrusions as well as the surrounding granitic rocks. The diabase is uniform, medium-to coarse-grained in sills, and fine-grained in dykes, with a green-grey to brown-grey colour. It consists of augite and labradorite, olivine and minor magnetite, serpentine and "iddingsite" and is moderately magnetic (Kaye, 1969). Several fine-grained mafic dykes cutting the Lac des Iles complex were found to contain green amphibole, plagioclase and magnetite.

PLEISTOCENE AND RECENT DEPOSITS

Glacial till, sand and gravel deposits are widespread in the area, especially in low lying areas. A few eskers are present, oriented approximately southwest (Pye, 1968).

STRUCTURAL GEOLOGY

Folding

The only recognizable folds in the Lac des Iles area are isoclinal and occur in the bands of meta-volcanics and metasediments to the south and east of Lac des Iles. For a detailed discussion of the fold style of the region the reader is referred to Pye (1968) and Kaye (1969).

It is not clear whether or not folding has affected the mafic intrusion in the area. Pye (1968) suggested that the metasediments in the Max Creek map-area were wedged apart by the intrusion of the Legris Lake body, to explain the present map pattern. This may suggest that the mafic intrusions were emplaced after the major episode of folding.

Layering in gabbro of the Lac des Iles complex is steeply dipping. If the complex was emplaced after the major folding episode, its present orientation could be due to deformation accompanying the emplacement of the granitic rocks.

Faulting

Faults of two orientations are present in the Lac des Iles area, those which trend northeast parallel to the Archean metavolcanics and those faults which strike north-northeast, cross-cutting the Archean formations (Pye, 1968).

Two faults which parallel stratigraphy are shown on figure 2 north of Legris Lake. The more northerly is defined by a topographic lineament and strongly fractured and altered granite some of which contains disseminated pyrite and specularite (Pye, 1968).

Oblique faults striking approximately 030° cut the gabbro, metavolcanics and metasediments at Legris Lake and displace the gabbro-metasediment contact there. Movement on both faults was left-hand several hundred metres (Pye, 1968).

Other oblique faults of similar orientation to those at Legris Lake are present further south cutting the metavolcanic belt and at Demars Lake and Wakinoo Lake where they partially control the outcrop pattern of the mafic intrusions.

A left-hand fault striking roughly 100° , defined by a topographic lineament is present at the southwest corner of Lac des Iles (Pye, 1968). To the east, the south shore of Lac des Iles and the mafic-ultramafic contact are linear and may reflect the continuation of this fault.

GEOLOGY OF THE LAC DES ILES COMPLEX

ULTRAMAFIC INTRUSION

The ultramafic intrusion occupies the northern half of the complex and extends about 100 metres south of the south shore of Lac des Iles. It is composed of serpentinite, peridotite, clinopyroxenite and websterite (Streckheisen, 1973) with minor amounts of gabbro, norite and anorthosite. These rock types are crystal cumulates which contain varying proportions of olivine, clinopyroxene, orthopyroxene, plagioclase and oxides. Variable amounts of secondary serpentine, amphibole, talc, sericite, zoisite and carbonate are present in most rock types.

Serpentinite

Serpentinite occurs in several outcrops on the east shore of Lac des Iles. It is green-black on a fresh surface and white to pale grey on a weathered surface with thin black streaks composed of magnetite. Veins of chrysotile with fibres up to 2 centimetres long are present in one outcrop. In thin section it is seen to be composed entirely of serpentine (lizardite and antigorite) and magnetite which is concentrated in zones composed of thin stringers (figure 4a).

Figure 3. Geology of the Lac des Iles Complex showing location of the Roby zone (after Anacanda Ltd., Texasgulf Canada Ltd. and Pye, 1968).

LEGEND

PRECAMBRIAN

PROTEROZOIC

KEWEENAWAN

DIABASE

ARCHEAN

GRANITIC ROCKS

WEBSTERITE

PYROXENITE

PERIDOTITE

EASTERN GABBRO

WESTERN GABBRO

GABBRO

GEOLOGICAL CONTACT

FAULT

Figure 4. Photomicrographs of ultramafic rocks.

Horizontal dimension D=7.0 mm.

- a. LDI-75-41. Serpentinite; lizardite and magnetite, plane polarized light.
- b. LDI-G-75-25. Peridotite; serpentized olivine, magnetite, clinopyroxene, crossed nicols.
- c. LDI-75-20B. Clinopyroxenite; clinopyroxene, partially altered to amphibole, crossed nicols.
- d. LIA-75-72. Websterite; cumulus orthopyroxene, intercumulus clinopyroxene, crossed nicols.

Peridotite

Peridotite occurs in three large bodies at the east side of the ultramafic intrusion and as several smaller pods and layers totalling approximately thirty percent of the exposed area (figure 3). It has a black-green fresh surface, termed "lustre mottled" by Pye (1968) due to the presence of shiny green grains of pyroxene set in a fine-grained matrix of serpentized olivine. In thin section the olivine is nearly completely altered to serpentine plus magnetite while the pyroxene is only slightly altered (figure 4b). Both clinopyroxene and orthopyroxene are present.

Clinopyroxenite

Two varieties of pyroxenite are present in the ultramafic intrusion, clinopyroxenite and websterite. Clinopyroxenite is the predominant lithology, comprising roughly 50 percent of the exposed area (figure 3).

It is composed of greater than ninety percent augite, largely as cumulus grains, with minor amounts of olivine, orthopyroxene and plagioclase (figure 4c). With an increase in olivine at the expense of augite it grades into peridotite. Clinopyroxenite is invariably coarse-grained and quite strongly altered to fine amphibole; minor amounts of chlorite and sericite may also be present (Pye, 1968).

Websterite

Websterite, a rock composed of near equal proportions of orthopyroxene and clinopyroxene, outcrops on islands near the centre of the ultramafic intrusion (figure 3). It is generally medium-grained, fresh and forms more prominent outcrops than the other ultramafic rocks. Orthopyroxene and clinopyroxene are both present as cumulus minerals; however in some websterites clinopyroxene occurs as an intercumulus mineral (figure 4d). Plagioclase is usually present, sometimes in amounts greater than 10 percent, so that some outcrops of websterite grade into mafic augite norite. Minor amounts of magnetite, spinel and secondary talc and amphibole are often present. Winfield and Workman (1976) reported apple-green olivine in a sample of websterite but none was found in this study.

Gabbro

Gabbro outcrops in an elongate zone at the eastern margin of the ultramafic intrusion and in two narrow northeast trending zones at the east side of the intrusion. Several other gabbroic pods are present throughout the complex. The gabbro is generally coarse-grained, composed of nearly equal amounts of plagioclase and clinopyroxene which are moderately saussuritized and uralitized. Several medium to large blocks of gabbro are present as inclusions in

clinopyroxenite along the south shore of Lac des Iles and in peridotite (figure 12c) on an island in the southern part of the lake (Watkinson, 1975).

Norite

Small irregular bodies of augite norite occur on islands in the websterite core of the intrusion. They are fresh and medium-grained as is the websterite. Several zones of norite and augite norite are present near the gabbro layers east of the lake. They are too small to be shown at the scale of figure 3.

Anorthosite

One large outcrop of anorthosite and felsic gabbro occurs on a point along the east shore of Lac des Iles. It contains five to fifteen percent clinopyroxene and several pyroxene megacrysts up to fifteen centimetres in length.

Layering

The terminology of Jackson (1967) will be used to describe layering in the Lac des Iles complex.

Layering in the ultramafic intrusion is recognizable at map-scale (figure 3) by the distribution of peridotite on the large island in the northwest and of peridotite, gabbro and norite zones east of Lac des Iles.

At the outcrop scale, many peridotite layers are apparently isomodal but some show vague to moderate mineral grading involving olivine and clinopyroxene. In some cases peridotite grades into clinopyroxenite without any discernable contact.

Size-graded layering was observed south of Lac des Iles in outcrops of clinopyroxenite which contain gabbroic inclusions, on the north shore of the large peninsula north of the websterite core, as well as in other areas. Layers vary in thickness from approximately 2 to 20 centimetres and, on the peninsula, grade laterally into massive clinopyroxenite.

A form and phase contact separates coarse-grained clinopyroxenite from medium-grained websterite which occupies the core of the intrusion. The websterite appears massive at outcrop scale suggesting that it occurs as thick isomodal layers.

Most layering dips away from the margin of the intrusion; however no simple pattern emerges of the original shape of the intrusion.

A ring of elongate islands at the north end of Lac des Iles, too small to show at map scale, has layering oriented tangentially to the ring. It may represent a late subsidiary ultramafic intrusion as suggested by Pye (1968).

Faulting

Faults have been identified striking at approximately 035° parallel to the long narrow bays on the east shore of Lac des Iles opposite the websterite core. Winfield and Workman (1976) have interpreted the steep cliffs on the northwest side of these bays to be a reflection of this faulting. They have further suggested that the granite tongues that project northeasterly from the west side of the intrusion may be surface expressions of a topographic high in the granite-ultramafic contact and that the faulting may be related to this. A magnetically low anomaly on the aeromagnetic map coincides with this proposed ridge in granitic basement. This structural high divides the ultramafic intrusion into northern and southern halves. The northern half is sub-circular in outline and shows a more concentric distribution of rock types than does the southern half.

Ultramafic-Mafic Contact

The contact between the ultramafic intrusion and the gabbro to the south is marked by a strong lineament on the aeromagnetic map. On the ground-magnetic survey map (figure 5) the eastern gabbro shows up strongly due to the presence of oxide-rich layers whereas the ultramafic has only a weak expression.

Outcrops of clinopyroxenite along the south shore of Lac des Iles contain many large angular inclusions of gabbro. It is interpreted that the ultramafic body intruded the eastern and western gabbros. The order of intrusion is western gabbro, eastern gabbro and ultramafic body.

It is uncertain to what extent the fault noted to the west of the ultramafic-mafic contact may have modified the original form of this contact.

WESTERN GABBRO

The western gabbro is the larger of the two mafic intrusions, extending from the south shore of the lake to the southern extremity of the complex. In contrast to the eastern gabbro, it displays only a weak pattern of anomalies on the ground magnetic survey map (figure 5). It contains layers of gabbro, norite, clinopyroxenite and anorthosite in decreasing order of abundance. They are cumulates of varying proportions of cumulus plagioclase, orthopyroxene and inter-cumulus clinopyroxene. Clinopyroxene occurs as a cumulus mineral in clinopyroxenite. Sulfides, oxides and secondary talc, amphibole, sericite, zoisite are present.

Layering in the western gabbro strikes 160° and is steeply dipping, varying from approximately 50°E to 85°E . It will be discussed in detail in chapter 4.

The geology of the southern part of the western

gabbro is known only from surface mapping. The scarcity of outcrop makes it impossible to compare it directly with the Roby zone. There appear to be the same rock types present although there may be a greater abundance of noritic rocks (Guarnera, 1967).

Gabbro

Gabbro forms approximately 70 percent of the western gabbro. It is coarse-grained to pegmatitic and contains nearly equal amounts of cumulus plagioclase ($An_{80}-An_{82}$) and intercumulus augite. Mafic gabbro gradational to clinopyroxenite and felsic gabbro gradational to anorthosite are also present. Clinopyroxene is generally strongly uralitized; amphiboles have the composition of hornblende or actinolite (Watkinson, 1975). Chlorite is often associated with the secondary amphibole forming a rim around the amphibole. Plagioclase in gabbros is completely fresh to strongly altered; alteration products are sericite; epidote and chlorite. Some gabbros contain orthopyroxene and a complete range exists between gabbro and norite.

Norite

Noritic rocks constitute approximately 20 percent of the western gabbro. Norites are generally medium-grained and are interlayered with gabbro, bronzite gabbro and augite norite. Bronzite gabbro has orthopyroxene composing 25 to 50 percent of the total

pyroxene content and augite norite has orthopyroxene composing 50 to 75 percent of the total pyroxene (table 3). These noritic rocks are also generally medium-grained and with the norite are generally fresh to weakly altered even when in contact with strongly altered gabbro.

Orthopyroxene, where altered, is rimmed and cut by veins of talc plus magnetite. In some layers complete talc pseudomorphs of orthopyroxene are present. Mineral-graded layering is present in the noritic units and some thin layers approach the composition of orthopyroxenite.

Clinopyroxenite

Clinopyroxenite occurs as several layers forming perhaps 10 percent of the western gabbro. These layers occur on the eastern side of the intrusion in the Roby zone. They are interlayered with gabbro and mafic gabbro and generally show sharp ratio contacts. Clinopyroxenite is composed of greater than 90 percent clinopyroxene now completely altered to fine-grained amphibole pseudomorphs. Minor secondary chlorite, epidote and carbonate are also present.

Anorthosite

Only a minor amount of anorthosite is present in the western gabbro, generally as differentiates in gabbroic layers. The majority of the plagioclase is cumulus; intercumulus material is plagioclase and

augite. Minor secondary sericite, epidote, chlorite and amphibole are generally present.

Sulfides in the western gabbro

Sulfides are irregularly distributed throughout all rock types of the western gabbro and are abundant in several mineralized zones (appendix A; figure 22). The main minerals present are pyrite, chalcopyrite, pentlandite, millerite and pyrrhotite in decreasing order of abundance. They occur in disseminated intercumulus blebs up to 1.5 centimetres across; in addition net-texture sulfide occurs sporadically in norite layers.

Primary, secondary and metamorphic sulfide assemblages are present and are host to platinum-group minerals, of which 11 have been identified from the Roby zone. Sulfides and PGM of the Roby zone will be discussed in detail in chapter 5.

Western gabbro-Eastern gabbro Contact

The contact between the eastern and western gabbros is known only from drill core as the two units were not distinguished in any surface mapping. The contact shown in figure 3 was drawn from projected drill hole contacts and by comparison with the ground magnetic survey map (figure 5). Level plans drafted using data from sections clearly indicate that the eastern gabbro crosscuts layering in the western gabbro. Rocks of both intrusions are sheared near the contact and often have a bleached appearance. Weakly altered, epidote-bearing, medium-grained gabbro dykes cutting the western gabbro may be equivalents of the eastern gabbro.

EASTERN GABBRO

The eastern gabbro is located south of Lac des Iles and is intrusive into the western gabbro. It is composed of layers of gabbro and norite; several of the latter are oxide-rich giving rise to a strong pattern of concentric anomalies on the ground magnetic survey map (figure 5). Drilling of the eastern gabbro intersected several coarse-grained zones with some minor platinum-group mineralization. These are interpreted to be large inclusions of the western gabbro.

Figure 5. Ground Magnetic Survey Map of Eastern Gabbro

Gabbro

Gabbro is invariably medium-grained and equigranular. No pegmatitic pods were recognized thus making it texturally distinct from gabbros of the western intrusion. Both plagioclase ($An_{52}-An_{60}$) and clinopyroxene are present as cumulus phases in the eastern gabbro although most clinopyroxene is intercumulus. Alteration of plagioclase to sericite and epidote and of clinopyroxene to amphibole and chlorite is weak to moderate but in general eastern gabbros are less strongly altered than those of the western unit. Most epidote is granular, formed during deuteric alteration of plagioclase; however some euhedral, coarse grains are present showing yellow to pale yellow pleochroism and are interpreted to be of metamorphic origin.

Norite

Noritic layers in the eastern intrusion are medium-grained and fresh, composed of cumulus plagioclase and orthopyroxene. Most contain clinopyroxene and some have the composition of augite norite. Weak alteration of orthopyroxene to talc plus magnetite and also to amphibole is common. Layers close to the margin of the intrusion contain abundant oxide and one layer 5 to 10 metres thick is composed predominantly of magnetite, ilmenite, green spinel and

minor pyroxene. Orthopyroxenes from the eastern gabbro are more iron-rich than those from the ultramafic and western intrusions, having compositions in the range $En_{62.5}$ to $En_{64.5}$ (Watkinson et al., 1979).

Sulfides in the Eastern Gabbro

The eastern gabbro is characterized by a paucity of sulfide; only rare pyrite was noted as disseminated grains and in shears with epidote and chlorite. The only exception to this is adjacent to the contact with the western gabbro where chalcopyrite and pyrrhotite are also found. Figure 7 shows Cu, Ni and PGE values in DDH P-97 which cuts both the western and eastern gabbros. Cu shows a peak at the contact but is otherwise negligible in the eastern gabbro. Ni and PGE values are extremely low throughout the eastern gabbro, except in inclusions as noted above. A summary of the differences between the western and eastern gabbros is presented in table 2.

	Western Gabbro	Eastern Gabbro
Lithologies	Gabbro, norite, clinopyroxenite, anorthosite and intermediate types	Gabbro, norite and intermediate types Basal magnetite-ilmenite-spinel-rich layer
Textures	Medium-grained to pegmatitic Euhedral cumulus minerals in intercumulus Pegmatitic lenses in zones parallel to layers Many small shear zones-amphibole, chlorite abundant	Medium-grained, uniform, equigranular, no pegmatitic pods, some shearing-yellow-green epidote, chlorite and amphibole present Generally fresher than western gabbro
Layering	Steeply-dipping, trending 160° Mineral-graded, chemical-graded and size-graded layers are present	Concentric pattern but orientation poorly known Mineral-graded layers present
Magnetic Expression	Weak-anomalies trending approximately 160°	Very strong concentric pattern following margin of intrusion
Sulfides	Abundant disseminated grains of cpy, py, pn, mill po. Accumulations at bases of graded layers, rare net texture in norite Coarse-grained in shear zones, especially py	Rare, fine disseminated grains of py, also cpy at contact with western gabbro
Assays	Cu, Ni very variable from .01 to .25 wt. % Pt-group variable from NIL to 30.0 ppm.	Cu from Trace to .01 wt. % Ni, Pt-group from NIL to Trace

Table 2 Comparison of western and eastern gabbros.

GEOLOGY OF THE ROBY ZONE

INTRODUCTION

The Roby zone is that portion of the western gabbro immediately west of the eastern gabbro which is enclosed in the rectangle shown in figure 4. The zone, as outlined, is 1220 metres by 270 metres and its southern end as designated in this thesis overlaps the western end of the "C zone" of Texasgulf Canada Ltd.

The Roby zone is composed of layers of gabbro (70%), norite (20%), clinopyroxenite (10%) and anorthosite (minor), striking at approximately 160° . Dips vary from approximately 65°E at the north end of the zone to 80°E near the centre, then back to 55° to 60°E near the south end.

Texasgulf Canada Ltd. drilled 103 holes to investigate Cu-Ni-Fe and platinum-group mineralization in the Roby zone (figure 6). Surface projections of all drill holes referred to in this study are plotted (solid circles) along with the positions of all holes drilled in the Roby zone (open circles).

Drill hole P-57 was selected for detailed study. It was collared in the eastern gabbro and drilled at -45° at an azimuth of 251° , penetrating approximately 30 metres of eastern gabbro before entering the mineralized zone of the western gabbro. Layering in

Figure 6. Location of drill holes in the Roby zone.

this part of the Roby zone dips east at approximately 65°.

PETROGRAPHY OF DRILL HOLE P-57

Three groups of rocks are present in the western intrusion. In decreasing order of abundance they are:

1. plagioclase cumulates
2. orthopyroxene-plagioclase cumulates
3. clinopyroxene cumulates

The plagioclase cumulates and clinopyroxene cumulates have been grouped together and classified on the basis of the proportion of plagioclase to clinopyroxene without regard for which of the two is the cumulus phase. A complete range of lithologies is present, from anorthosite to clinopyroxenite. The five rock types distinguished and their compositional ranges are listed in table 3. Only a few layers of clinopyroxenite and mafic gabbro contain cumulus clinopyroxene.

The orthopyroxene-plagioclase cumulates have been subdivided on the basis of the proportion of orthopyroxene to clinopyroxene. In nearly all cases orthopyroxene is present only as a cumulus phase. Clinopyroxene is present in these rocks only as an intercumulus phase. Felsic and mafic varieties of the "noritic" group have not been distinguished because in general, all noritic rocks contain between

Table 3 . Classification of rock types of the western gabbro.
(modified after Texasgulf Canada Ltd.)

Plagioclase cumulates			Clinopyroxene cumulates		
Anorthosite	Felsic Gabbro	Gabbro	Mafic Gabbro	Clinopyroxenite	
<10% cpx	10-30% cpx	31-70% cpx	71-90% cpx	>90% cpx	
Orthopyroxene-Plagioclase cumulates					
Gabbro	Bronzite Gabbro	Augite Norite	Norite	Orthopyroxenite	
opx/opx+cpx<25%	26-50%	51-75%	>75%	>90%	

30 and 70 percent total pyroxene. Only two thin layers of orthopyroxenite are present in a sequence of mineral-graded norites.

In the Roby zone, the general sequence of cumulates from west to east is the same as that listed above so that gabbro, with cumulus plagioclase, predominates on the west side of the zone. Orthopyroxene-plagioclase cumulates are located centrally in the zone and clinopyroxene cumulates are on the eastern side near the contact with the eastern gabbro.

In drill hole P-57 gabbro predominates near the bottom of the hole, noritic rocks near the middle and clinopyroxenite close to the top, in contact with the eastern gabbro. Figure 8 shows the distribution of lithologies in P-57, the composition of the orthopyroxene, the cumulus phases present, and the copper, nickel and platinum-group values.

Disseminated sulfides are irregularly distributed throughout all the rock types of the western intrusion and are occasionally sufficiently concentrated in norite to form a net texture.

Gabbro

Gabbro of the western intrusion is coarse-grained and composed of variable amounts of cumulus plagioclase and intercumulus clinopyroxene. The clinopyroxene is strongly to completely altered to fine-grained fibrous amphibole. The amphibole is usually oriented

Figure 7. Rock types and Cu, Ni, P.G.E. values in DDH P-97.

Figure 8. Rock types, pyroxene chemistry, cumulus minerals
and Cu, Ni and PGE values in DDH P-57.

LEGEND

DIABASE

EASTERN GABBRO

ANORTHOSITE

FELSIC GABBRO

GABBRO

MAFIC GABBRO

CLINOPYROXENITE

BRONZITE GABBRO

AUGITE NORITE

NORITE

parallel to the clinopyroxene "C" direction and often forms pseudomorphs of the intercumulus grains (figure 6b). Oikocrysts of clinopyroxene up to 2.5 centimetres in length contain many tens of cumulus plagioclase grains. Amphibole formed from clinopyroxene has the composition of either actinolite or hornblende (Watkinson, 1975).

Large fresh grains of pleochroic hornblende, showing a well developed cleavage are also present, apparently intercumulus to plagioclase. These are interpreted to be products of metamorphism, perhaps of an earlier alteration product of clinopyroxene. The possibility exists that some hornblende may be primary.

Plagioclase is often unaltered in the gabbro but usually there is some sericitization of rims or cores (figure 9b). In some cases the process has gone to completion and only a sericite pseudomorph remains in a mass of fine-grained amphibole.

Chlorite occurs as veinlets cutting plagioclase grains and with amphibole as an alteration product of clinopyroxene. It often occurs in a zone between plagioclase and secondary amphibole and as an alteration product after plagioclase.

Epidote occurs in minor amounts as fine-grained granular material associated with sericitized plagioclase.

Figure 9. Photomicrographs of rocks of western gabbro
in plane polarized light.

Horizontal dimension D=7.0 mm.

- a. P-57-109.0. Clinopyroxenite; fine-grained amphibole pseudomorphic after cumulus clinopyroxene.
- b. P-57-224.5. Gabbro; cumulus plagioclase, intercumulus clinopyroxene altered to fine-grained amphibole.
- c. P-57-259.5. Augite-norite; cumulus plagioclase and orthopyroxene, intercumulus clinopyroxene.
- d. P-57-156.7. Norite; cumulus plagioclase and orthopyroxene, minor intercumulus plagioclase and clinopyroxene.

clase and is often in contact with secondary oxides.

Sulfide in gabbro occurs as irregularly distributed blebs and very fine-grained material interstitial to secondary silicates. In one sequence of size-graded layers in drill hole P-99 sulfide is present at the coarse-grained base of each layer in amounts up to 3 percent (figure 11); however this occurrence is extremely rare.

Felsic Gabbro

Felsic gabbro is coarse-grained, rarely pegmatitic and contains between 10 and 30 percent intercumulus clinopyroxene. It is only a minor constituent of the western intrusion, generally occurring in association with very thin layers of anorthosite. Felsic gabbro is generally as strongly altered as the enclosing gabbro and the same secondary minerals are present.

Subhedral outlines of cumulus plagioclase are only obvious where they are in contact with intercumulus clinopyroxene or its alteration products. Plagioclase is often granulated, and its original cumulus texture is thus destroyed. Late adcumulus plagioclase has obscured early plagioclase crystal outlines except where there has been sericitization of the margins of the early grains.

In one thin section small subhedral cumulus

plagioclase was observed as an inclusion in a large cumulus plagioclase. In the same section the size distribution of cumulus plagioclase appears to be bimodal.

Mafic Gabbro

Mafic gabbro contains 71 to 90 percent clinopyroxene. It occurs as discrete layers (or lenses) in the gabbroic rocks as well as with clinopyroxenite.

Mafic gabbro in the gabbro apparently contains no cumulus clinopyroxene, is only marginally more mafic than the associated gabbros and is altered to the same degree. Development of chlorite at the expense of plagioclase occasionally gives the rock a dark green colour, especially where shearing has occurred, making its distinction from clinopyroxenite difficult.

When associated with clinopyroxenite the mafic gabbro is composed of cumulus clinopyroxene, nearly completely altered to fine-grained amphibole, with greater than 10 percent plagioclase, both cumulus and intercumulus. The two rock types are often sheared giving rise to a rock composed almost entirely of chlorite and amphibole and cut by many chlorite-filled fractures.

Clinopyroxenite

Clinopyroxenite is composed of fine-grained amphibole pseudomorphic after coarse-grained subhedral

cumulus clinopyroxene. Interstitial to these pseudomorphs are masses of medium-grained chlorite occasionally with oxide, sulfide and epidote that formed from original intercumulus plagioclase or clinopyroxene. Sulfide occurs in amounts up to 5 percent and is intercumulus, partially enclosing pyroxene pseudomorphs (figure 9a). Some mobilization has occurred as sulfide also occurs in the pseudomorphs in thin streaks parallel to the secondary amphibole. A trace amount of biotite is present.

Anorthosite

Anorthosite, containing greater than 90 percent plagioclase occurs as thin layers in gabbro and felsic gabbro. It appears fresher than them due to the smaller amount of intercumulus augite. Plagioclase appears to be bimodal with large cumulus grains, often strained or broken, separated by small rounded grains which are fresh and unstrained. The large grains are only slightly altered to sericite.

Clinopyroxene, altered to fine-grained amphibole, forms angular intercumulus patches. One anorthosite layer contains approximately 5 percent interstitial chalcopyrite moulded around plagioclase grains.

Bronzite Gabbro

Bronzite gabbro occurs in several isomodal layers in the western gabbro and as layers transitional between gabbro and augite norite in graded

Figure 10. Geological Section 521.

sequences. Both types of layers are present in section 521 (figure 10).

Plagioclase and orthopyroxene are both present as cumulus minerals although in one thin section orthopyroxene is apparently intercumulus; no evidence was seen to suggest overgrowths on original cumulus grains.

Orthopyroxene compositions in noritic rocks range from En_{71} to En_{79} as shown in figure 8. Only one grain was analysed from bronzite gabbro and it has the composition En_{76} .

Augite is the predominant intercumulus mineral as in gabbro and is generally weakly to moderately altered to fine-grained amphibole and chlorite.

Augite Norite

Augite norite is a medium-grained rock containing between 30 and 70 percent pyroxene of which orthopyroxene constitutes 50 to 75 percent. The distribution of augite norite in P-57 is shown in figure 8. It occurs as thick layers with norite that are gradational into it, as at P57-80, and as uniform layers gradational over a few centimetres into orthopyroxene-free gabbro, as at P57-60. The facies change from bronzite gabbro to norite shown in figure 10 involves some rocks having the composition of augite norite. As well, most norite

layers shown have some sections of augite norite.

Orthopyroxene and plagioclase both occur as cumulus minerals in augite norite while clinopyroxene forms small patches of intercumulus material and occasionally oikocrysts up to 2.5 centimetres in length containing many tens of small subhedral orthopyroxene (figure 9c). Plagioclase is present in minor amounts as an intercumulus mineral, rarely as overgrowths on cumulus plagioclase.

Augite norite generally shows practically no alteration, but orthopyroxenes are often cut by talc-magnetite veins, the magnetite occurring in the centre of the vein.

Clinopyroxene is weakly to strongly altered to fine-grained amphibole and chlorite and plagioclase is rarely altered to sericite. Veins of chlorite cut both plagioclase and clinopyroxene and are continuous with the talc-magnetite veins in orthopyroxene.

Sulfide is present as small, intercumulus blebs, often slightly mobilized in the more strongly altered layers where it is intergrown with secondary silicates.

Norite.

Norite in the western gabbro is medium-grained, usually fresh, containing between 30 and 70 percent pyroxene of which greater than 75 percent is ortho-

pyroxene. It occurs in isomodal layers varying from approximately 1 to 15 metres in thickness and in layers gradational to augite norite, or in rare cases, orthopyroxenite.

Orthopyroxene and plagioclase are cumulus minerals with some plagioclase present as intercumulus material as well. Large cumulus orthopyroxene grains often contain small euhedral (early cumulus) plagioclase grains (figure 9d). Orthopyroxene falls in the range En_{73} to En_{79} (figure 8) and plagioclase in the range An_{79} to An_{82} (bytownite) as in augite norite.

Clinopyroxene (augite) forms small patches of intercumulus material; alteration, where present, is as described above for augite norite. Usually only small veins cutting orthopyroxene and some alteration of the rims of clinopyroxene are observed.

Disseminated sulfide is common in norite; rarely it is present in sufficient abundance to form a net texture enclosing cumulus orthopyroxene. The common assemblage in fresh norite is pyrite-pentlandite-pyrrhotite-chalcopyrite.

LAYERING IN THE ROBY ZONE

Jackson (1967) discussed four types of layers and three types of contacts separating them that he used to describe cumulates in the Stillwater, Great Dyke and Bushveld intrusions. He noted that cumulate layers do not approximate the composition of the magma from which they crystallized and that the composition and character of cumulus and intercumulus material are virtually independent.

All the types of layers and contacts described by Jackson (1967) are present in the western gabbro. In addition, a second variety of mineral-graded layer is present characterized by a change in the proportion of one cumulus mineral and intercumulus material. Similarly a second type of ratio contact is present marked by a sharp change in the proportion of one cumulus mineral and intercumulus material.

Plagioclase, orthopyroxene and clinopyroxene occur as cumulus minerals in the western gabbro. Plagioclase is a cumulus mineral in all rock types except clinopyroxenite. Orthopyroxene is a cumulus mineral in norite, augite-norite and bronzite gabbro. Clinopyroxene is a cumulus mineral in clinopyroxenite and some mafic gabbro layers.

All variations in rock types present are due to changes in the proportions of one or two cumulus

minerals and the associated intercumulus material. Clinopyroxene is the predominant intercumulus mineral in gabbroic and noritic rocks. Minor amounts of plagioclase, orthopyroxene, sulfide and oxide also occur as intercumulus material.

Mineral-Graded Layers

Mineral grading, involving a change in the proportions of two cumulus minerals, orthopyroxene and plagioclase, is often observed in the noritic layers of the Roby zone. Layers of norite containing close to 70 percent orthopyroxene grade into layers containing only about 30 percent orthopyroxene so that distinct colour differences are observed in one thick norite unit. These felsic and mafic varieties grade into each other over short vertical distances and each layer may be only 10 to 20 centimetres thick. In some sequences norite contains very thin layers of orthopyroxenite which contain 5 to 10 percent sulfide, occasionally forming a net texture.

In general no sharp bases to the layers were observed; even the orthopyroxenite grades in both directions into norite, then felsic norite, so that they cannot be used to determine the stratigraphic top of the intrusion. The change in the proportion of orthopyroxene to plagioclase could be a result of convection currents acting on the less dense plagio-

Figure 11. Graded layers in gabbro

A. DDH P-99 Size-graded layers (cumulus clinopyroxene)

B. DDH P-48 Mineral-graded layers (cumulus plagioclase)

Figure 12. Photographs of layering in DDH P-48

- a. Clinopyroxenite layer (at 51.0 metres)
in coarse-grained gabbro.
- b. Anorthosite layer (at 90.3 metres) with
increase in plagioclase concentration down
the hole producing a sharp contact with the
overlying gabbro.
- c. Inclusion of layered felsic gabbro in
peridotite.

clase and redistributing it or it could be due to a short halt in the crystallization of plagioclase.

The gradation from ~~gabbro to bronzite~~ gabbro to augite norite to norite represents a mineral-graded sequence involving a continuous increase in the ratio of cumulus orthopyroxene to intercumulus clinopyroxene. However no repetition of layers of this sort is known in the Roby zone; only the occasional mineral-graded layer is present in a thick unit of gabbro.

Mineral-graded layers involving a change in the proportion of cumulus plagioclase and intercumulus augite are present in gabbro resulting in the formation of thin anorthosite units. These are well displayed in drill hole P-48 (figure 11, 12b). The gabbro becomes increasingly felsic in each mineral-graded layer, culminating in a 15 to 30 centimetre thick anorthosite layer.

Mineral grading also results in the formation of felsic gabbro layers which have a greater proportion of cumulus plagioclase than the enclosing gabbro.

Size-graded Layers

Size-graded layers have been observed in gabbro and norite of the western intrusion. The best example of these is present in gabbro in drill hole P-99 (figure 11). This hole was drilled at a low angle to the layering so thicknesses of layers are exaggerated

but 7 size-graded layers are recognizable. Clinopyroxene is the size-graded cumulus mineral and the coarse-grained base of each layer contains intercumulus oxide and sulfide. They may, therefore, be reliably used to indicate that the facing direction of the western intrusion is to the east.

Size grading in noritic layers is sporadic but several layers of norite were observed with cumulus orthopyroxene up to 2.5 centimetres in length in P-104.

Chemical-Graded Layers

Microprobe analyses of orthopyroxene from augite norite and norite layers in drill hole P-57 indicate a range of compositions from En_{72} to En_{79} (figure 8). The iron enrichment trend displayed by orthopyroxene in norite at P57-80, over a narrow stratigraphic interval, indicates that chemically-graded layers do occur in the western intrusion. However, more analyses would have to be done at more closely spaced intervals to define layers.

Isomodal Layers

Layers of uniform composition and proportion of cumulus minerals occur in the western intrusion. Bronzite gabbro occurs as discrete isomodal layers and displays a sharp phase contact with orthopyroxene-free gabbro.

Layers of clinopyroxenite near the eastern side of the Roby zone are occasionally isomodal, composed of greater than 90 percent clinopyroxene. They display a sharp phase contact with gabbro which has no cumulus clinopyroxene. In other cases, clinopyroxenite grades into mafic gabbro first which is separated from gabbro by a phase contact.

Lateral Variation in Layering

In drawing the sections presented as figures 10 and 13 consideration was given to which layers had the same cumulus minerals rather than to which had the same composition or proportion of minerals. This was done because the change from clinopyroxenite to mafic gabbro, for example, would only require a minor amount of intercumulus liquid to be trapped by the settling crystals. This could reasonably be expected to occur to differing degrees in different parts of the intrusion.

Detailed drilling revealed that many layers, especially thinner ones, pinch out both along strike and down dip making detailed correlations between drill holes difficult. In section 521 (figure 10), for example, the thickest norite layer in P-57 becomes thinner and poorer in orthopyroxene down dip, grading into a bronzite gabbro, as observed in P-49, (with minor intermediate augite norite not shown at this

Figure 13 Geological Section 515.

scale) and finally into orthopyroxene-free gabbro. P-92 at this depth contains no orthopyroxene-bearing layers. At a still greater depth P-36 intersected a thick norite layer down dip from the layer intersected by P-57 and P-49. While definite correlation of these two layers is not certain they each must pinch out.

Sections further to the south show all the noritic layers to be thinning dramatically so that by section 515 (figure 13), 183 metres south of section 521, only one thin lens of bronzite gabbro is present west of the clinopyroxenite layers. Two short units of norite are also reported in the long clinopyroxenite unit in P-103. Their origin is uncertain but they could represent inclusions rather than layers.

Gradational relationships are also shown in section 515 (figure 13) by the presence of lenses of mafic gabbro in gabbro and of clinopyroxenite grading down-dip into mafic gabbro.

Pegmatitic Zones

Gabbros of the western intrusion are highly variable in grain size, ranging from coarse-grained to pegmatitic. Pegmatitic zones are abundant in the western gabbro and vary from approximately 10 centimetres to 5 metres in thickness. They generally show sharp contacts with the enclosing gabbros.

Pegmatitic zones in adjacent drill holes occasionally are at the same stratigraphic level suggesting that they may be layers or at least pod-like bodies that formed contemporaneously. The only associated cumulus mineral is plagioclase in the overlying and underlying gabbros. The pegmatitic gabbro contains subhedral grains but not in an obvious cumulate texture. Sulfide is present in some pegmatitic zones as coarse blebs up to 3 centimetres in diameter; however it is generally not more abundant than in adjacent gabbros.

Shear Zones

Shear zones, varying in width from 1 centimetre to several metres, have been noted in the western gabbro cutting gabbro and other related rocks but rarely noritic rocks. The primary mineralogy and texture have been destroyed and the assemblage chlorite-amphibole predominates. In some shears carbonate, sericite and epidote are also abundant. As observed in drill core, the shear zones are randomly oriented and cannot be correlated between drill holes. They do not appear to have disrupted the igneous stratigraphy and are interpreted to have developed late, perhaps during intrusion of the eastern gabbro.

PYROXENES OF THE WESTERN GABBRO

Orthopyroxene occurs as a cumulus mineral in discrete layers in the western gabbro. These layers range in composition from bronzite gabbro to norite and contain varying amounts of intercumulus augite. The orthopyroxene generally has an oval to subhedral outline and is fresh, or, less commonly, slightly altered to the assemblage talc-magnetite along fractures. Grain size varies from 1 millimetre to 2 centimetres but most are in the range 2 to 5 millimetres. They are pale brown in plane polarized light and strongly pleochroic from pink to pale green under crossed nicols. Cumulus orthopyroxene occasionally contains small subhedral (cumulus) plagioclase grains. Large irregular grains of orthopyroxene (P57-213.3) may be intercumulus. No outlines were seen to suggest overgrowths on cumulus grains. This orthopyroxene is intercumulus to plagioclase.

No inverted pigeonite was observed in the western gabbro; however it is present in the ultramafic body.

Clinopyroxene occurs intercumulus to plagioclase and orthopyroxene throughout the western gabbro except in a few pyroxenite layers at the east side (stratigraphic top) of the Roby zone where it is the cumulus mineral (figure 8). In some augite-norite layers clinopyroxene occurs as oikocrysts up to 3 centimetres

long enclosing many tens of grains of cumulus orthopyroxene and plagioclase. In gabbro and clinopyroxenite it is strongly altered to fine-grained aggregates of amphibole and chlorite.

2 PYROXENE CHEMISTRY

Clinopyroxene and orthopyroxene from bronzite gabbro, augite norite and norite layers of the western gabbro were analysed by electron microprobe (Watkinson et al., 1979). Samples were taken over a stratigraphic thickness of 40 metres.

All orthopyroxenes of the western gabbro have the composition of bronzite (figure 15). Analyses were done at closely spaced intervals in the hope of finding cryptic layering. Although the wide range of compositions (En_{72} to En_{79}) suggests that cryptic layering may be present and several sharp discontinuities in orthopyroxene composition are present (figure 14), no repetition of an Fe-enrichment trend was found with increasing stratigraphic height. Compositions of the rims of orthopyroxene grains often varied by approximately two percent enstatite from the composition of the cores.

CaO-content of orthopyroxene varies from 0.39 to 2.82 weight percent (appendix F, table 1). Ti and Zn contents are low in orthopyroxenes of the western

Figure 14. Compositions of orthopyroxene and plagioclase from DDH P-57 and pyroxene equilibration temperatures. e=edge of grain

gabbro. MnO reaches a maximum of 0.37 weight percent (appendix F, table 1, number 14) and has been added to Fe for the purpose of plotting figure 15.

Clinopyroxenes from the noritic layers of the western gabbro all fall in the compositional range of augite and have a restricted range of Fe:Mg, but their Ca-content varies considerably (figure 15). This range may be due to non-equilibrium crystallization or to alteration. Clinopyroxenes from gabbroic layers of the western gabbro are too strongly altered to amphibole-chlorite assemblages to be analysed.

Pyroxenes of the western gabbro overlap the range of compositions found in pyroxenites of the ultramafic intrusion. Peridotites from the ultramafic body contain the most Mg-rich pyroxenes of the Lac des Iles complex (figure 15).

Clinopyroxenes and orthopyroxenes of the eastern gabbro are significantly more Fe-rich than the most Fe-rich pyroxenes of the western gabbro (figure 15). In sample P116-207.9 of the eastern gabbro the cores of clinopyroxenes are more Ca-rich than the rims, i.e. they are normally zoned, however in sample P116-73.6 the rims are more Ca-rich than the cores.

Figure 15. Compositions of pyroxenes from the Lac des Iles complex.

Orthopyroxenes analysed from gabbroic inclusions in the ultramafic body plot with those of either the western or the eastern gabbro but do not span the range between the two gabbros (figure 15). This is consistent with other evidence that suggests that the ultramafic intrudes both the gabbro bodies.

The composition of clinopyroxene from gabbroic inclusions demonstrates the same division noted above, plotting with either the western or eastern gabbro (figure 15).

PYROXENE THERMOMETRY

The experimental data for the diopside-enstatite miscibility gap were fitted by Wells (1977) to a linear equation between $\ln K$ and $1/T$ where K is the equilibrium constant and T the temperature in degrees centigrade. He used an ideal two-site mixing model for $Mg_2Si_2O_6$ between ortho- and clinopyroxene following that of Wood and Banno (1973). The mixing model was chosen that best fitted the experimental data. To take account of Al in the pyroxenes the activity of the $Mg_2Si_2O_6$ component in the ortho- and clinopyroxene phases was calculated by Wells assuming that Al substitutes for Mg and Si on the X and Z sites respectively with complete coupling between octahedral and tetrahedral Al to maintain local charge balance. Wells

(1977) found that for Al contents less than 12 weight percent, $\ln K$ was not related to the amount of Al present in the pyroxenes. Wells' model gave temperatures consistent with most of the available experimental data over the temperature range 785 to 1500 degrees centigrade and composition range $X_{Fe}^{opx} = 0.0$ to 0.85. He concluded that the model should give calculated temperatures accurate to 70 degrees centigrade provided the conditions are within these ranges.

A computer program was prepared by Dr. P.R. Mainwaring for the model of Wells (1977). Total Al was divided between the Z and (X+Y) sites so that the Z site was filled and the remaining Al put in the (X+Y) sites. For an acceptable analysis (X+Y) should be 2.00; in most cases (tables 4 and 5) the total departs from 2.00 in only the second decimal place.

Temperatures were obtained for pairs of coexisting ortho- and clinopyroxenes from:

1. norites from DDH P-57 in the western gabbro
2. augite norites from DDH P-116 in the eastern gabbro
3. peridotite, pyroxenite and websterite from the ultramafic body
4. gabbroic inclusions in the ultramafic body

Temperatures of about 1100 degrees centigrade were obtained for pyroxenes from the peridotite and of

Table 4. Pyroxene temperatures from the western and eastern gabbros.

P-57	ORTHOPIYROXENE		CLINOPYROXENE		TEMP. °C
	#	X + Y	#	X + Y	
156.7A	1	2.005	1	1.995	820
156.7B	2	1.991	2	2.010	855
156.7C	3	1.987	3	2.008	784
159.4A	5	2.004	4	2.000	727
159.4B	6	2.001	4	2.000	726
190.5	9	2.052	7	2.010	868
199.0	11	1.996	8	1.994	1066
214.5	13	2.010	9	2.013	814
259.5A	17	1.989	11	2.022	952
259.5B	17	1.989	12	2.005	907
262.3	20	1.993	14	1.997	954
270.2	23	2.010	16	2.001	899

Specimen numbers from appendix F.

P-116	ORTHOPIYROXENE		CLINOPYROXENE		TEMP °C
	#	X + Y	#	X + Y	
73.6 207.9	8c	2.014	9c	2.012	880
	8r	2.035	9r	2.028	949
	10c	2.032	11c	2.010	832
	10r	2.005	11r	1.999	966
	1c	2.035	1c	2.046	969
	1r	2.039	1r	2.052	896
	2c	2.025	2c	2.033	943
	2r	2.010	2r	2.044	821
	3c	2.038	3c	2.022	1016
	3r	2.045	3r	2.030	966

Specimen numbers from Watkinson et al. (1979)

c=core, r=rim.

SAMPLE ROCK TYPE	ORTHOPYROXENE		CLINOPYROXENE		TEMP °C
	#	X + Y	#	X + Y	
LDI-4-1a Peridotite	3-4a	2.020	3-4	2.043	1117
4-1b Peridotite	3-4b	1.983	3-4	2.043	1099
5-2 Pyroxenite	4-1a	2.006	4-1	1.981	1032
	4-1b	2.021	4-1	1.981	1031
	4-1c	2.014	4-1	1.981	1033
	4-1d	1.997	4-1	1.981	1035
14-1 Websterite	6-1	2.032	6-1	2.030	916
	6-2	2.026	6-2	2.015	1050
	6-3r	2.027	6-3	2.016	1018
	6-3c	2.035	6-3	2.016	1017

Specimen numbers from Watkinson (1975)

In websterite c=core, r=rim.

GABBROIC INCLUSIONS IN ULTRAMAFIC BODY					
6-1a	12-1	2.035	13-1	2.025	913
	12-4	2.039	13-2	2.031	941
6-1b	12-5r	2.026	13-3r	2.008	1085
	12-6c	2.027	13-4c	2.032	947
	12-9	2.032	13-5	2.001	1079

Specimen numbers from Watkinson et al. (1979)

c=core, r=rim.

Table 5. Pyroxene temperatures from the ultramafic body and gabbroic inclusions.

1030 degrees centigrade for the pyroxenite (table 5). Temperatures obtained for the western gabbro ranged from 1066 to 726 degrees centigrade while those for the eastern gabbro were consistently around 950 degrees centigrade (table 4). Pyroxenes from gabbroic inclusions in the ultramafic body gave temperatures in the same range as those of the ultramafic body.

SUMMARY.

Plagioclase, orthopyroxene-plagioclase and clinopyroxene cumulates occur progressively further east in the steeply-dipping Roby zone, corresponding to original increasing stratigraphic height in the intrusion. Plagioclase cumulates range in composition from anorthosite to mafic gabbro, clinopyroxene cumulates from mafic gabbro to clinopyroxenite and orthopyroxene-plagioclase cumulates from bronzite gabbro to orthopyroxenite (rare). Clinopyroxene in gabbroic rocks is generally strongly altered to chlorite-amphibole assemblages whereas noritic rocks are weakly altered or fresh.

Size-graded, mineral-graded, chemical-graded and isomodal layers are present in the Roby zone. Mineral-graded layers involve changes in the proportions of two cumulus minerals or one cumulus mineral and intercumulus material. Layers vary in composition laterally with some layers pinching out; noritic layers, especially, are abundant in some sections through the Roby zone and thin or absent from others.

Pegmatitic zones are abundant in gabbroic rocks of the Roby zone and it appears that some have lateral continuity. They do not contain an obvious cumulus mineral or a large amount of sulfide. Shear zones, where primary textures are destroyed and the assemblage

chlorite-amphibole predominates, occur irregularly in the Roby zone, mainly cutting gabbroic rocks.

Orthopyroxene in the western gabbro is bronzite and varies in composition from En_{72} to En_{79} . Clinopyroxene is augite with a considerable range of Ca-contents. Pyroxenes in the western gabbro overlap the compositional range of those from pyroxenites of the ultramafic body but are significantly more magnesian than pyroxenes of the eastern gabbro. Calculated pyroxene equilibration temperatures are progressively lower for peridotite, pyroxenite and western gabbro. The ranges of values obtained are small for all rock types except the western gabbro, perhaps due to the presence of fluid during crystallization of the western gabbro liquid.

COPPER-NICKEL-IRON AND PLATINUM-GROUP ELEMENT
MINERALIZATION

INTRODUCTION

Sulfides occurring in the Roby zone in approximate order of decreasing abundance are pyrite, chalcopyrite, pentlandite, pyrrhotite, millerite, violarite, vysotskite, sphalerite and galena (based on 50 polished sections). Assemblages of these occur in disseminated blebs usually less than one centimetre in diameter, but occasionally larger, in all rock types (except diabase). The blebs are distributed irregularly and are most abundant in some layers of clinopyroxenite and norite. Sulfides rarely form a net texture and only in norite and orthopyroxenite.

Pyrite, magnetite and chalcopyrite are locally abundant in a shear zone where the sulfide concentration is approximately forty percent. Small shear zones and veinlets of secondary silicates often contain pyrite and chalcopyrite, the former frequently as lacy porphyroblasts. These minerals also form halos of very fine-grained material in secondary silicates surrounding a sulfide bleb, or thin stringers aligned with secondary amphibole in pyroxene pseudomorphs.

Pentlandite and pyrrhotite rarely occur as fine disseminated grains with secondary silicates. Usually they form the bulk of a sulfide bleb, often intergrown with pyrite and chalcopyrite. Grains of sphalerite and galena were seen only rarely during this study.

SULFIDE MINERAL ASSEMBLAGES

Sulfide mineral assemblages present in the Roby zone are:

1. pyrrhotite-pentlandite-pyrite
2. pyrrhotite-pyrite
3. pentlandite-pyrite
4. pentlandite-millerite-violarite
5. pentlandite-millerite
6. pyrite-millerite
7. pyrrhotite-pentlandite-pyrite (-millerite)
8. pyrite

Chalcopyrite is ubiquitous and is the only Cu-bearing mineral present.

Assemblages 1, 2 and 3 each occur as sulfide blebs in gabbro and norite. Most net-textured sulfide in norite contains assemblage 3 or, less commonly, assemblage 1; pyrrhotite is often absent from pentlandite-bearing assemblages. Pentlandites analysed from assemblage 1 contain approximately 28 atomic percent Ni (appendix G, table G-2, figure 17), in agreement with Misra and Fleet's (1973) data. Where pyrrhotite and pentlandite occur together they often form a polygonal network of grains or, less commonly, pyrrhotite forms large grains separated by thin zones of fine-grained pentlandite. Flames of pentlandite are occasionally present near the edge of large pyrrhotite grains.

Figure 16. Sulfide assemblages present in the Roby zone.
Fe-Ni-S system, atomic percent.

Assemblage 4 (pentlandite-millerite-violarite, figures 16, 17) is found in sulfide blebs in strongly altered gabbros. Pentlandite, millerite and violarite are all present as large, fresh, inclusion-free grains which have smooth grain boundaries against each other. No violarite is present along the octahedral fractures of pentlandite where alteration would likely occur first. The violarite is lavender in color and microprobe analyses show that it is Co-rich (appendix G, table G-3). Three analyses have Co in excess of Fe and so some grains should properly be termed ferroan siegenite. The low totals reported may be due to the presence of an element not sought for in the violarite. A range from 8.9 to 11.9 weight percent Co was found in this study; however J.H.G. Laflamme has analysed "violarites" from the western gabbro containing up to 18 weight percent Co (pers. comm., 1978). The associated pentlandite contains a maximum of 0.13 weight percent Co and 42.5 to 43.5 weight percent Ni (appendix G, table G-2) which agrees with Misra and Fleet (1973). Grey Co-poor violarite was noted in another section, occurring as fine ragged grains along fractures in pentlandite.

Assemblage 5 (pentlandite-millerite) is common and often occurs in the same section of core as assemblage 4. It commonly contains fine-grained lacy pyrite formed as a product of the breakdown of pentlandite.

Figure 17: Sulfide assemblages and associated PGM from the Roby zone (atomic percent). For mineral abbreviations see appendix D

Assemblage 6 was noted in only one section where it occurred in several small blebs. Assemblage 5 was also present in the same polished section. The millerite is coarse-grained, forming sheafs of blade-like grains, either entirely enclosed within chalcopyrite or in contact with both chalcopyrite and the surrounding silicate.

Assemblage 7 is the same as assemblage 1 except that some fresh, smooth-bordered millerite grains have formed, apparently at the expense of pentlandite. It was observed in one polished section.

Assemblage 8 is very common in strongly altered gabbros where it occurs in small blebs; both pyrite and chalcopyrite occur as fine disseminations in secondary silicates.

SUMMARY - HISTORY OF SULFIDES IN THE ROBY ZONE

A four-stage history for the sulfides in the Roby zone is indicated by the assemblages observed. These stages can be correlated with the silicate history.

1. Magmatic stage - Exsolution on cooling

Assemblages 1, 2 and 3, which are predominant in fresh to weakly altered noritic rocks are thought to represent exsolution from primary magmatic monosulfide solid solution (MSS). Analyses of coexisting pyrrhotite-pentlandite-pyrite (figure 17) and exsolution textures between pyrrhotite and pentlandite are consistent with

them having crystallized from MSS.

2. Deuteric alteration - Mobilization of Pd, Cu, Fe, S

Little evidence remains of this stage as sulfides recrystallized during the later metamorphism but the abundance of fine disseminated grains of pyrite and chalcopryrite with secondary amphibole and chlorite and the presence of trains of pyrite porphyroblasts leading out along fractures from sulfide blebs suggests that Fe and Cu were preferentially removed from the original magmatic blebs. Some Pd was mobilized as well because fine grains of vysotskite occur with chalcopryrite and pyrite in the secondary silicates. Ni was less mobile and remained behind to give rise to the Ni-rich assemblages 4, 5 and 6 during later metamorphism.

Primary magmatic assemblages which crystallized in the western gabbro presumably were altered at the same time that uralitization of pyroxene and saussuritization of plagioclase was taking place. This likely was caused by late fluids from the crystallizing intrusion; however it could have been a result of the transfer of heat and movement of fluids during the intrusion of the eastern gabbro.

3. Metamorphism

The majority of violarite and millerite occurrences in association with pentlandite and chalcopryrite (assemblage 4, figure 16) cannot have been formed by a simple

alteration process. Both violarite and millerite are inclusion-free, are as coarse-grained as the pentlandite and chalcopyrite, and have smooth, sharp grain boundaries. The lack of appreciable Co content in the pentlandite combined with the Co-rich nature of the violarite strongly suggests that the assemblage pentlandite-millerite-violarite (-chalcopyrite) is of metamorphic origin, probably from an earlier altered (oxidized) assemblage, and that the cobalt preferentially entered the violarite.

The assemblage pyrite-millerite-sphalerite-galena-vysotskite in P22-380 is interpreted to have been metamorphosed. The metamorphic assemblages pyrite-millerite and pentlandite-violarite-millerite apparently involve conflicting tie-lines (figure 16); however the Co-rich nature of violarite in the latter assemblage may mean that it is stable in the quaternary system Fe-Ni-Co-S.

The metamorphism, which reached greenschist conditions, may have occurred during the emplacement of the surrounding Kenoran granitic rocks.

4. Supergene

A small amount of late-stage alteration of the sulfide assemblages noted above is present. It may be associated with the emplacement of the diabase dykes and

sills but no spatial relationship with these was determined in this study. Grey violarite occurs along fractures in pentlandite and a minor amount of secondary pyrite forming at the expense of pentlandite is also present in some sections.

PLATINUM-GROUP MINERALS

The first PGM identified from the Lac des Iles complex was vysotskite, $(\text{Pd},\text{Ni})\text{S}$, found in association with millerite, pyrite, chalcopyrite, sphalerite and galena (Watkinson, 1975).

Cabri and Laflamme (1976a) studied ore-mineral concentrates from the Roby zone and identified 8 PGM. These were vysotskite; kotulskite, PdTe ; merenskyite, PdTe_2 ; sperrylite, PtAs_2 ; moncheite, PtTe_2 ; isomertieite, $\text{Pd}_8(\text{As},\text{Sb})_3$; stillwaterite, Pd_8As_3 ; and an unnamed mineral, Pd_5As_2 . They also found palladium in solid solution in melonite, gold and pentlandite.

Six PGM were identified in this study as well as several unknown minerals occurring alone or as inclusions in vysotskite. Table 6 lists these minerals, their optical properties, occurrence and representative microprobe analyses.

Vysotskite

The most abundant PGM in the Roby zone is vysotskite, $(\text{Pd},\text{Ni})\text{S}$. More grains of it were found in this study than of all the other PGM combined. Following the

MINERAL	DESCRIPTION		PROBE ANALYSIS	OCCURRENCE
	COLOUR	ANISOTROPY		
Vysotskite	Bluish-white	Faint; blue to brown	(Pd .80, Ni .21, Fe .01, Pt .01, S .97)	exsolved from pn rod-like grains in cp in silicates
Braggite	Bluish-white	Faint; blue to brown	(Pd .62, Pt .23, Ni .16, S .99)	with pn and vysotskite
Kotulskite	Bireflectant buff-yellow to whitish-yellow	Strong; grey-blue to yellow	(Pd .96, Ag .04, Pt .01, Te .80, Bi .19)	with merenskyite and $Ag_4Pd_3Te_4$ and alone in cp
Merenskyite	white	Strong; blue to yellow	(Pd .01, Pt .01, Ni .01, Te .1, Bi .32) *	intergrown with kotulskite and $Ag_4Pd_3Te_4$.
Un named $Ag_4Pd_3Te_4$	Grey-brown (Brown in oil)	Moderate; orange-brown to yellow-green	$Ag_4.00Pd_3.08$ (Te .3, Bi .04) *	intergrown with kotulskite and merenskyite.
Stibiopalladinite	Buff-yellow	Moderate; yellow to brown	(Pd .5, Ni .02, Sb .1, As .37, Te .32) *	intergrown with kotulskite
Unknown A	white	Isotropic	—	intergrown with brown mineral.
Unknown B	brown	Moderate; yellow to grey	—	Inclusions in vysotskite.
Unknown C	grey	Isotropic	—	Inclusion in vysotskite.

Table 6. Optical properties, analyses and occurrence of PGM and 3 unidentified minerals. * J.H.G. Laflamme, analyst, 1978.

2 2
OF/DE

terminology of Cabri et al. (1978) the term vysotskite is restricted to those minerals of general formula $(\text{Pd}, \text{Pt}, \text{Ni})\text{S}$ that contain less than ten atomic percent Pt. Minerals with greater than ten percent Pt and the same crystal structure are termed braggite.

Vysotskite occurs commonly in pentlandite, either as discrete anhedral grains or in a lamellar intergrowth with pentlandite, suggesting an exsolution origin (figure 18b,d). Vysotskite also occurs in chalcopyrite as rod-shaped grains with a square cross-section (figure 18c). These grains have pentlandite exsolved perpendicular to their long axis and in the core of square grains. In the same sample lamellar vysotskite is intergrown with (and presumably exsolved from) pentlandite and is entirely enclosed within it. The pentlandite grain is enclosed within a large bleb of chalcopyrite.

While the ideal composition of vysotskite is PdS , electron microprobe analyses of vysotskites from the Roby zone show that most contain appreciable Ni and a minor amount of Pt (appendix H, table H-2). Ni in vysotskite varies from 9.4 to 11.3 weight percent. Most vysotskite contains less than 2.0 weight percent Pt, but in several grains analysed, Pt was much higher. In one grain (figure 18a) the arbitrary limit of 19.5 weight percent Pt (10 atomic percent) was reached. One

spot analysed in this inhomogeneous grain had 30 weight percent Pt; thus the grain ranges in composition between vysotskite and braggite.

Braggite

Braggite, $(\text{Pd,Pt,Ni})\text{S}$, is optically identical to and isomorphous with vysotskite. It is distinguished from vysotskite solely on the basis of composition, having greater than 10 atomic percent Pt (Cabri et al., 1978).

Five spots were analysed on one large $(\text{Pd,Pt,Ni})\text{S}$ grain using the electron microprobe. Of these, three gave compositions in the range of braggite and two in the range of vysotskite. The five spots ranged from 4.0 to 15.7 atomic percent Pt (figure 19, P75). The maximum variation determined by Cabri et al. (1978) on an inhomogeneous grain was approximately 14 to 40 atomic percent Pt. It is possible that some grains identified optically as vysotskite in this study may be braggite.

Kotulskite

Kotulskite, PdTe , is the most abundant telluride in the Roby zone. It is found as homogeneous anhedral grains in chalcopyrite and pentlandite (figure 20a,b,c) and in complex intergrowths with merenskyite and an unnamed mineral of composition $\text{Ag}_4\text{Pd}_3\text{Te}_4$ (figures 20c,d 21a,b).

A representative microprobe analysis for kotulskite intergrown with merenskyite and $\text{Ag}_4\text{Pd}_3\text{Te}_4$ is $(\text{Pd,Ag})_{0.97}$

Figure 18. Photomicrographs of PGM in plane polarized light in oil. Horizontal dimension $D=0.12\text{mm}$.

- a. P75-383.4. Inhomogeneous vysotskite-braggite grain in pentlandite (with pentlandite inclusions).
- b. P96-227.4. Large vysotskite grain and lamellar intergrowth of vysotskite and pentlandite.
- c. P96-227.4. Rod-shaped grains of vysotskite with pentlandite inclusions, in chalcopyrite.
- d. P96-227.4. Intergrowth of pentlandite, vysotskite (medium grey) and chalcopyrite (dark grey).

Figure 19. Composition of vysotskite and braggite (atomic percent)
 Single spot analyses; those from P75 are from a single
 grain referred to on pages 82,83.

(Te,Bi)_{1.03}, and for single phase grains of kotulskite in chalcopyrite is (Pd,Pt,Ni)_{0.99}(Te,Bi)_{1.01}, (appendix H, table H-1).

Merenskyite

Merenskyite, PdTe₂, was found in complex grains in a lamellar intergrowth with kotulskite and unnamed Ag₄Pd₃Te₄ (figure 21a,b) and rimming kotulskite and unnamed Ag₄Pd₃Te₄ (figure 20d). It is very similar to kotulskite in its optical properties but is slightly whiter in plane polarized light. Merenskyite in figure 21a was analysed by microprobe by J.H.G. Laflamme at the CANMET laboratory and gave: (Pd_{1.01}Pt_{0.01}Ni_{0.01})_{1.03}(Te_{1.66}Bi_{0.32})_{1.98}, calculated on the basis of three atoms.

Unnamed Ag₄Pd₃Te₄

This mineral, first reported from the Levack West mine, Sudbury area, by Cabri and Laflamme (1976b), occurs in several grains complexly intergrown with kotulskite and merenskyite (figure 21a,b). This is the second occurrence of this mineral. It is grey-brown in air, medium brown in oil and moderately anisotropic from yellow-green to orange-brown (not weakly anisotropic as previously reported by Cabri and Laflamme, 1976b). On re-examination of the original grain from the Levack West mine it was found that it is, indeed, moderately anisotropic (L.J. Cabri, pers. comm., 1978). He con-

Figure 20. Photomicrographs of PGM in oil under crossed nicols. Horizontal dimension D=0.12mm.

- a. P58-322.1. Kotulskite grains at chalcopyrite-pentlandite grain boundary. Other small kotulskites in chalcopyrite.
- b. P58-322.1. Kotulskites in chalcopyrite and secondary silicates.
- c. P58-322.1. Elongate kotulskites along chalcopyrite-silicate contact. Large kotulskite with merenskyite (light grey) and unnamed $\text{Ag}_4\text{Pd}_3\text{Te}_4$.
- d. P59-520.4. Kotulskite and $\text{Ag}_4\text{Pd}_3\text{Te}_4$ (dark grey) rimmed by merenskyite, enclosed in anisotropic twinned chalcopyrite.

Figure 21. Photomicrographs of PGM in oil

- a. P58-322.1. Horizontal dimension $D=0.09\text{mm}$.
plane polarized light.
Intergrown kotulskite,
merenskyite and unnamed
 $\text{Ag}_4\text{Pd}_3\text{Te}_4$ in chalcopyrite.
- b. P58-322.1. $D=0.12\text{mm}$, crossed nicols.
Same grain as in (a).
Intergrowth of merenskyite (me)
and kotulskite (ko).
- c. P75-384.2. $D=0.12\text{mm}$, crossed nicols.
Kotulskite grains, one with
round brown inclusion uni-
dentified, enclosed in
pentlandite and secondary
silicates.
- d. P75-384.2. $D=0.12\text{mm}$, crossed nicols.
Stibiopalladinite (st) with
grains of kotulskite (circled) in
pentlandite with lacy py-
rite. Several stibiopal-
ladinite grains have many
small kotulskite inclusions.

cluded that a typographic or printing error may have occurred in the original report. Analysis by microprobe at CANMET by J.H.G. Laflamme gave $\text{Ag}_{4.00}\text{Pd}_{3.08}(\text{Te}_{3.88}\text{Bi}_{0.04})_{3.92}$ as an average of nine spots on two grains from Lac des Iles.

Stibiopalladinite

Stibiopalladinite, $\text{Pd}_{5+x}\text{Sb}_{2-x}$, occurs with kotulskite in a complex grain associated with pentlandite, Co-rich violarite and pyrite (figure 2ld). It forms smooth-sided anhedral grains, buff yellow in plane polarized light in air and in oil. It is strongly anisotropic from yellow to brown. Several grains are full of fine kotulskite inclusions. Two inclusion-free grains of stibiopalladinite analysed by J.H.G. Laflamme at CANMET gave $(\text{Pd}_{5.03}\text{Ni}_{0.02})_{5.05}(\text{Sb}_{1.26}\text{As}_{0.37}\text{Te}_{0.32})_{1.95}$ calculated on the basis of seven atoms.

Unknown A

Unknown A is a brilliant white, isotropic mineral of which only one small curved grain was found in this study. It is intergrown with a brown mineral. The white mineral could be a PGM or perhaps an arsenide.

Unknown B

Unknown B is brown, moderately anisotropic from yellow to grey and occurs in two inclusions in a small vysotskite grain in secondary silicate. In one inclusion chalcopyrite is also present.

Unknown C

This mineral is grey, isotropic and occurs at the corner of the vysotskite grain that contains unknown B.

Gold

Native gold was found with pyrite porphyroblasts in a sulfide-rich shear zone in altered gabbro and as ragged grains in a heavy mineral fraction separated from a norite containing 0.5% sulfide.

Palladium in pentlandite

Palladium was sought for but not detected in pentlandite grains analysed at 20 kilovolts and approximately .05 microamperes using a counting time of 10 seconds. It is not certain whether the grains analysed contained no palladium or the counting time was too short. J.H.G. Laflamme (pers. comm., 1978) used 25 kilovolts and a 50 second counting time to determine palladium in pentlandite. The highest value he obtained was 0.65 atomic percent Pd; however many pentlandite grains analysed contained no Pd (limit of detection 0.02 atomic percent).

Correlation of rock type and Cu, Ni and PGE values

Assay intervals in drill holes in the western gabbro do not, in general, correspond to individual layers so little can be said in detail about the relationship between PGE concentrations and individual rock types.

However, there is an apparent correlation of peaks in PGE (and Cu and Ni) values with mafic rock types, especially norite, in some parts of the Roby zone. This correlation could be explained by a model linking S solubility in the magma to the activity of FeO. The latter would decrease with the precipitation of a mafic mineral causing the solubility of S to decrease. With a decrease in S solubility, immiscible sulfide droplets would form (Maclean, 1969). These, which serve to collect PGE and other rare elements such as Te, Bi and Sb, would precipitate to the floor of the magma chamber where they would be incorporated into the layer of accumulating pyroxenes.

It is possible that sulfide droplets, because of their density, could settle through an unconsolidated cumulate layer via the intercumulus liquid so that the correlation is not always 1:1 with cumulate mafic minerals.

Occasional lack of correlation of PGE with Cu, Ni and S could be due to the occurrence of platinum-group arsenides or other minerals independent of the sulfides through mobilization of PGE.

SUMMARY - OCCURRENCE OF PGM IN THE ROBY ZONE

Most vysotskite observed in this study occurs in Ni-sulfide assemblages; usually pentlandite is the host. The only exception is the rod-shaped grains in chalcopyrite; however even they have inclusions of exsolved pentlandite and several are enclosed in small

islands of pentlandite in the large chalcopyrite bleb. Vysotskite may have exsolved from MSS but the lamellar intergrowths commonly observed between vysotskite and pentlandite suggest that there may have been a high temperature precursor to the exsolved products.

Vysotskite also occurs as very fine grains disseminated in secondary silicates with chalcopyrite and lacy pyrite porphyroblasts. Unknowns B and C occur with this secondary vysotskite.

Far fewer grains of kotulskite, merenskyite and $\text{Ag}_4\text{Pd}_3\text{Te}_4$ than vysotskite were found in this study. Most of the tellurides occur in chalcopyrite in the assemblage chalcopyrite-pentlandite-pyrrhotite-pyrite, which is interpreted to be primary. Any of the tellurides not found in chalcopyrite are in pentlandite (7 grains). In the section containing stibiopalladinite, kotulskite occurs in a ragged sulfide bleb of pentlandite and Co-rich violarite. This assemblage is interpreted to be metamorphic. Pyrite has formed late at the expense of pentlandite. In addition, kotulskite occurs intergrown with stibiopalladinite and as fine inclusions in it.

DISCUSSION - HISTORY OF THE WESTERN GABBRO

The Lac des Iles complex is composed of three intrusions, the western gabbro, eastern gabbro and ultramafic body. The western gabbro was the first emplaced and is composed of layers of gabbro, norite, clinopyroxenite and anorthosite as well as rock types transitional to these. Few top indicators have been noted but some size-graded layers with sulfide and oxide-rich bases indicate that the steeply east-dipping intrusion faces east.

All the rock types are crystal cumulates; the cumulus minerals are plagioclase, orthopyroxene and clinopyroxene and they occur in this order with increasing stratigraphic height. Clinopyroxenites, which have clinopyroxene as the only cumulus mineral are cut off at the east side of the intrusion by the eastern gabbro. Clinopyroxene is present as an intercumulus mineral in all except a few norite layers. Plagioclase is intercumulus as well and occasionally adcumulus.

The central layers of the Roby zone are composed of norite, augite norite, bronzite gabbro and gabbro. Those lithologies represent changes in the proportion of cumulus orthopyroxene, plagioclase and intercumulus clinopyroxene. Norite grades into augite norite and augite norite into bronzite gabbro by a decrease in

the ratio of cumulus orthopyroxene to plagioclase. The percentage of clinopyroxene increases steadily through this sequence.

Noritic layers pinch out both along strike and down dip in the Roby zone. The lensoid nature of these layers suggests that cumulus orthopyroxene could have been transported by convection currents near the base of the magma chamber. Once deposited in a depression the mineral would be less likely to be removed because of its high specific gravity. Plagioclase grains were also present and, in some cases, could be winnowed out by strong currents to leave thin orthopyroxenite layers. Normally orthopyroxene and plagioclase accumulated together to form the noritic layers.

Variable amounts of cumulus plagioclase occur in the range of rock types from anorthosite to mafic gabbro. Anorthosites, containing more than 90 percent plagioclase, could have formed by the precipitation of plagioclase grains to the floor of the magma chamber or, as suggested by Vermaak (1976) for the Bushveld Igneous Complex, by the accumulation of a mat of plagioclase grains either floating on or suspended in the magma at the level with the appropriate specific gravity. Plagioclase is the only cumulus phase in gabbro; some graded layers have anorthositic tops and pass downwards into felsic gabbro and then gabbro (figure 11). Some of these layers have

sharp top contacts (figure 12b), others grade into gabbro in both directions. With few reliable top indicators (based on cumulus pyroxene) and examples where gradational and sharp contacts are both present in the same sequence of anorthosite layers, Vermaak's (1976) model of plagioclase suspension and accumulation in a magma cannot be either accepted or rejected for the Roby zone.

Pegmatitic zones are common in the western gabbro and contain no obvious cumulus mineral. While they occur in the mineralized zone they do not contain an unusual amount of PGE. These zones may have formed by either:

1. rapid accumulation of cumulus plagioclase on the floor of the magma chamber resulting in the trapping of some liquid below a mat of plagioclase crystals. This liquid would cool slowly allowing the development of coarse crystals or,

2. trapping of a volatile-rich liquid beneath a floating or suspended mat of plagioclase crystals as suggested by Vermaak (1976). Slow crystallization in the presence of volatiles would lead to a pegmatitic texture. The crystallized material would then presumably fall to the floor of the magma chamber. In either case outlined above, pegmatitic pods could be expected to occur at similar stratigraphic levels over a wide area.

An interesting feature of this deposit is the

paucity of spinels from the western gabbro in contrast to other platinum-group deposits (Vermaak, 1976). Only magnetite (and associated ilmenite) was noted in this study.

The large range of temperatures determined for the western gabbro may be a reflection of the presence of variable amounts of H_2O in the liquid during crystallization. Pyroxenes which crystallized from H_2O -rich magma may have equilibrated to lower temperatures. The higher temperatures of crystallization determined for the eastern gabbro in spite of the higher $Fe/(Fe+Mg)$ values in its pyroxenes suggests that it results from a separate magma injected after the emplacement of the western gabbro.

Augite grains with rims more calcic than the cores have been noted from the eastern gabbro. Hewins (1974) suggested that such reversed zoning, which he noted in the Sudbury irruptive, was due to equilibration with a late intercumulus fluid.

Alteration of the primary magmatic minerals to secondary assemblages is widespread in the western gabbro. Most gabbros contain no original clinopyroxene; in its place they have fine-grained aggregates of amphibole and chlorite. Plagioclase is variably saussuritized and orthopyroxene is often slightly altered to the assemblage talc-magnetite. The alteration and metamorphism, which has produced mineral assemblages

compatible with greenschist facies metamorphism, could be deuteric. The abundance of pegmatitic gabbro suggests the presence of a free gas phase at some stage during crystallization.

The magma for the western gabbro presumably was mantle-derived and had high initial concentrations of Cu, Ni, PGE, S and H_2O . Further concentration occurred in residual silicate and sulfide liquids. This is compatible with the variable grain size, occurrence of pegmatitic pods and pronounced deuteric alteration of the western gabbro and the wide range to low temperature of pyroxene equilibration temperatures.

Immiscible sulfide droplets served to collect PGE and other rare elements such as Te, Bi and Sb. On cooling, MSS precipitated from the sulfide liquid as well as possibly some intermediate solid solution and PGM. Pyrrhotite, chalcopyrite and pentlandite exsolved from MSS. The common intergrowths of vysotskite with pentlandite suggest that they may have had a single high-temperature precursor. The history of PGM in the Roby zone is similar to that of the host Cu-Ni-Fe sulfides.

Primary exsolution assemblages are present in fresh noritic rocks as well as in altered gabbro in large sulfide blebs that apparently were less affected by alteration.

Secondary assemblages, formed as a result of

mobilization by fluids are Fe and Cu-rich. Some Pd was also moved as PGM are found with fine-grained disseminated chalcopyrite and pyrite in chlorite-amphibole assemblages. These disseminations occur in halos around the large sulfide blebs and, in greater concentration, along fractures radiating from the blebs. Mobilization generally has occurred over a distance of several centimetres but, rarely has occurred on a larger scale. Some shear zones contain abundant sulfide.

Metamorphism of the residual Ni-rich sulfide blebs (after removal of some Fe and Cu) has produced the assemblages pentlandite-violarite and pentlandite-violarite-millerite. PGM occur with the latter assemblage.

Supergene alteration is not widespread in the Roby zone but violarite has developed to a minor extent at the expense of pentlandite. This may be related to the emplacement of the Keweenaw diabase or simply to percolation of meteoric waters.

Vysotskite is the predominant PGM occurring in the Roby zone. It is uncertain, from this study, what proportion of those grains optically identified as vysotskite contain variable amounts of Pt and range to braggite compositions. Braggite, moncheite and sperrylite (Cabri and Laflamme, 1976a) are the three platinum-rich PGM identified from the Roby zone: only braggite was observed in this study. Besides moncheite and sperrylite,

isomertieite, stillwaterite and unnamed Pd_5As_2 , identified by Cabri and Laflamme (1976a) were not observed whereas three PGM (unnamed $\text{Ag}_4\text{Pd}_3\text{Te}_4$, braggite and stibiopalladinite) were first identified from Lac des Iles in this study.

ACKNOWLEDGEMENTS

I wish to thank D.H. Watkinson for helpful advice and financial support which permitted me to complete this thesis. I am grateful to P.R. Mainwaring for his advice on the pyroxene thermometry and for acting as interim thesis supervisor. L. Whitmore assisted in the preparation of several figures.

Discussions with L.J. Cabri on platinum-group minerals and permission to use his mineral separation laboratory are much appreciated. J.H.G. Laflamme provided helpful advice on the analysis of several PGM and Ni-Fe sulfides and confirmed the identity of several PGM by quantitative probe analysis.

This study was initiated and supported by Texasgulf Canada Ltd. I wish to thank G.W. Mannard for his encouragement and G. MacVeigh and B. Winfield for useful discussions on the geology of the complex. J.P. Sheridan kindly permitted me to continue this study.

REFERENCES CITED

- CABRI, L.J. & LAFLAMME, J.H.G. (1976a): Ore microscopy of some samples from Lac des Iles, Ontario. Geol. Assoc. Canada. Program Abstr. 1, 56.
- _____, & _____. (1976b): The mineralogy of the platinum-group elements from some copper-nickel deposits of the Sudbury area, Ontario. Econ. Geol. 71, 1159-1195.
- _____, STEWART, J.M., TURNER, K. & SKINNER, B.J. (1978): On cooperite, braggite and vysotskite. Amer. Mineral., 63, 832-839.
- CHASSÉ, J.L. (1978): The petrology of the eastern part of the Lac des Iles complex, northwestern Ontario. B.Sc. thesis, Carleton Univ., Ottawa.
- GOODWIN, A.M. (1977): Archean volcanism in Superior province, Canadian Shield in Volcanic regimes in Canada (W.R.A. Baragar, L.C. Coleman and J.M. Hall, eds.). Geol. Assoc. Canada Spec. Paper 16, 205-241.
- GUARNERA, B.J. (1967): Geology of the McKernan Lake phase of the Lac des Iles intrusive, Thunder Bay District, Ontario. M.Sc. thesis, Michigan Tech. Univ., Houghton, Mich.
- HEWINS, R.H. (1974): Pyroxene crystallization trends and contrasting augite zoning in the Sudbury nickel irruptive. Amer. Mineral., 59, 120-126.
- JACKSON, E.D. (1967): Ultramafic cumulates in the Stillwater, Great Dyke, and Bushveld intrusions. in Ultramafic and related rocks (P.J. Wyllie, ed.), 20-38.
- KAYE, L. (1969): Geology of the Bayrs Lake-Starnes Lake area. Ont. Dep't. Mines Geol. Rep. 77.
- MACLEAN, W.H. (1969): Liquidus phase relations in the FeS-FeO-Fe₃O₄-SiO₂ System, and their application in geology. Econ. Geol. 64, 865-884.

- MISRA, K.C. & FLEET, M.E. (1973): The chemical compositions of synthetic and natural pentlandite assemblages. *Econ. Geol.*, 68, 518-539.
- PYE, E.G. (1968): Geology of the Lac des Iles area. *Ont. Dep't. Mines, Geology Rep.* 64.
- STRECKHEISEN, A.L. (1973): Plutonic rocks - classification and nomenclature recommended by the IUGS Subcommittee on the systematics of igneous rocks. *Geotimes* 18, 26-30.
- VERMAAK, C.F. (1976): The Merensky reef - Thoughts on its environment and genesis. *Econ. Geol.* 71, 1270-1298.
- WATKINSON, D.H. (1975): Report on the petrology and mineralogy, Lac des Iles complex, northwestern Ontario. Internal report to Texasgulf Inc.
- WATKINSON, D.H., DUNNING, G.R. & JOHAN, Z. (1979): Chemistry of pyroxenes from the Lac des Iles complex, northwestern Ontario. (in preparation)
- WELLS, P.R.A. (1977): Pyroxene thermometry in simple and complex systems. *Contr. Mineral. Petrol.* 62, 129-139.
- WINFIELD, B. & WORKMAN, A. (1976): Report on lake-shore mapping, Lac des Iles, October-November, 1975. Texasgulf internal report and map.
- WOOD, B.J. & BANNO, S.B. (1973): Garnet-Orthopyroxene and Orthopyroxene-Clinopyroxene Relationships in simple and complex systems. *Contr. Mineral. Petrol.* 42, 109-124.

APPENDIX A

PREVIOUS WORK

In 1923, Swanson mapped the geology along the Phillips and Benner 2nd meridian line which extends north from Lac des Iles, for the Ontario Department of Mines.

Also in 1923, Tanton mapped the geology along Block Creek and discovered a belt of Archean metavolcanics and sediments. This led, in 1933, to Jolliffe's reconnaissance mapping of the Block Creek map-area for the Geological Survey of Canada. The map, published at a scale of 1 inch to 2 miles, outlined a wide belt of metavolcanics and metasediments along the projected strike of the Long Lac-Sturgeon Lake belt. Jolliffe's map was the only one available for the region until further ODM mapping in the mid 1960's.

In 1958 and 1959, following an aeromagnetic survey which showed an anomaly at the north end of Lac des Iles, F.H. Jowsey Ltd. staked 80 claims. Four conductive zones were drilled and found to consist of magnetite in peridotite layers.

In 1963 two prospectors discovered Cu-Ni mineralization south of Lac des Iles and Gunnex Ltd. staked the area. In 1963 and 1964 the company mapped the area and conducted geochemical and geophysical surveys. Diamond drilling and trenching were carried out and

eight sulfide zones were delineated. Assay data indicated significant amounts of palladium and platinum to be present in several zones. The highest values noted by Pye (1968) were .032 ounces per ton platinum and 0.34 ounces per ton palladium from the C zone. The eight mineralized zones are shown in Figure 22.

Pye (1968) mapped the Lac des Iles and Max Creek map-areas in 1964 and 1965 for the Ontario Department of Mines and produced two maps at a scale of 1 inch to 1/2 mile. (O.D.M. Nos 2135, 2136) He described the mafic and ultramafic rocks of the Lac des Iles complex and presented chemical analyses. He also described the eight mineralized zones discovered by Gunnex Ltd.

In 1965 Anaconda American Brass Ltd. optioned the property, carried out a ground magnetic survey, and mapped the entire Lac des Iles complex. Further drilling was done before the company dropped the property in 1966. The company also explored the small mafic intrusion south of Demars Lake in the Eayrs Lake - Starnes Lake map-area. (Kaye, 1969)

Guarnera (1967) did a Master's thesis at Michigan Technological University in which he described the petrography of anorthosite and norite from a small area west of Mckernan Lake.

Figure 22 Mineralized Zones (after Pye, 1968) and location of the Roby zone.

Boston Bay Mines acquired the property in 1974 and drilled 35 holes in the mineralized zone. Phil Roby, an employee of Boston Bay Mines, correctly deduced the strike of the layering to be approximately 160° .

Texasgulf Canada Ltd. optioned the property from Boston Bay Mines in 1975 and remapped the entire Lac des Iles complex. Winfield and Workman (1976) reported on the geology of the ultramafic intrusion.

One hundred and eighteen holes were drilled, which outlined the main ore zone, the Roby zone (figure 22), and tested several other occurrences. Texasgulf dropped the Lac des Iles property in mid 1976.

Watkinson (1975) discussed some of the problems of the geology of the Lac des Iles complex in a report prepared for Texasgulf Canada Ltd. He examined one drill hole in detail and analysed silicate and sulfide minerals including vysotskite, a palladium-nickel sulfide.

Cabri and Laflamme (1976a) of CANMET, Department of Energy, Mines and Resources, examined heavy mineral concentrates from samples of the Lac des Iles core. They reported finding eight platinum-group minerals, and palladium in solid solution in melonite, gold and pentlandite.

In December, 1976, Boston Bay Mines drilled one

deep hole to check the vertical extent of the mineralization. Significant PGE values were encountered from 332 metres to 445 metres depth.

Chassé (1978) studied core from two holes (P-111, P-116) cutting the eastern gabbro for a B.Sc thesis at Carleton University.

APPENDIX B

PROCEDURE FOR SULFIDE CONCENTRATION

Samples of drill core from units with high PGE values, weighing from 70 to 100 grams, were crushed to thumbnail-sized chips using a rock hammer. These chips were fed through a jaw crusher which produced fine chips and powder. This material was then processed for 15 seconds in a grinding mill to produce a fine powder which was then sieved to give the five size fractions listed below:

<170, >200 mesh

<120, >170 mesh

<100, >120 mesh

<65, >100 mesh

>65 mesh

Any material that passed through the 200 mesh sieve was not processed further.

Each size fraction for each sample was processed in a separatory funnel filled with methylene iodide (specific gravity 3.3). The heavy minerals separated were run through the funnel a second time to remove any light minerals that adhered to them during the first descent. All size fractions were dried and then processed one sample at a time using an elutriation tube filled with methylene iodide. Each size fraction for each sample was processed through the

tube separately from coarsest to finest to minimize the possibility of coarse grains drawing down fine grains. As the minerals descended through the tube, the methylene iodide was pumped slowly up the tube, to add a drag effect. By adjusting the flow rate, the most dense heavy minerals could be made to settle while less dense ones remained in suspension. Thus, using a single heavy liquid, a far greater separation of phases of different densities could be achieved than by using a separatory funnel. This method had been developed by technical staff at the CANMET mineral separation laboratory.

The samples were dried and some size fractions recombined. Each resulting sample was mounted in a monolayer polished section for microscopic examination.

APPENDIX C

Petrography of rocks from the Roby zone
 tr=trace amount of mineral present
 C=cumulus mineral
 IC=intercumulus mineral.

Sample number P57-	Present mode										Original mode					
	op	cp	pc	hb	am	ch	bi	ep	cb	tc	se	mg	sl	op	cp	pc
86.1			40		10	10		5	tr		3	tr	tr		C, IC 20	C80
95.1			65		19	10		1	?		5	tr	tr		IC30	C70
102.9			10		60	10		10			10	?	tr		C60, C25 IC15	
109.0				tr	94	2	tr	1				tr	1		C95	IC5
118.7			25		38	20		2			15				C10, C40 IC50	
129.0			22	20	30	10		2			16				IC60	C40
133.2			60		10	2		9			18				IC15	C65, IC20
151.1			50	20	17	3	2	2			1	tr	1		IC40	C55, IC5
156.7	45	5	35	2	3	1	tr			5	2	tr		C50	IC10	C30, IC10
159.4	60	5	30	2		tr				1	tr	tr		C62	IC8	C25, IC5

Sample number	op	cp	pc	hb	am	ch	bi	ep	cb	tc	se	mg	sl	op	cp	pc
PS7-																
160.0	50	15	32	1		tr	tr			1		tr		C50	IC15	C27, IC5
161.3	34	2	50	2	1					8	2	1		IC42	IC5	C40, IC13
162.4	30	2	50	2	1					11	3	1		C40	IC5	C40, IC15
178.5			60	10	10	5				10	5			IC10	IC25	C45, IC20
190.5	30	10	47	2	3	1				5	2	tr		C35	IC15	C42, IC8
199.0	15	12	45	1	2	1				20	2	2		C20, IC16	IC15	C42, IC7
204.0			40	1	15	20		1			23				IC20	C60, IC20
213.3	15	15	65		1	1				2	1	tr		IC15	IC16	C62, IC7
214.5	8	15	70		2	1				3	tr	tr		C5, IC6	IC16	C65, IC8
224.5			44	25	10	10		1		tr	10				IC40	C50, IC10
243.0			55	10	15	20					tr				C30, IC15	C45, IC10
244.0			90	3	2						3				IC5	C80, IC15
257.2	30	3	62			1	tr			2	tr	tr	tr	C16, IC16	IC5	C51, IC12
259.5	30	50	17		tr					tr	tr		1	C31	IC51	C16, IC2
259.6	40	15	35	3	3	1	tr			tr	tr	tr	tr	C41	IC22	C32, IC5

Sample number	op	cp	hb	am	ch	bi	ep	cb	tc	se	mg	sl	op	cp	pc
P57-															
260.0	15	3	80	tr	tr				1		tr		IC16	IC4	C70, IC10
270.2	30	1	66	tr	tr		tr		1		tr		IC16,	IC2	C50, IC15
274.2			54	40	1	2	1				2		mafic dyke		
279.0	16		75	2	1	1			5		tr		IC21	IC3	C65, IC11
294.0			77	3	12	5	tr			2				IC17	C66, IC17
307.2			tr	9	70		10		5	1	2	3	dyke-gabbro contact		
316.4				3	75	15	2	?		5			C75	IC5	C5, IC15
325.1			20	5	25	15	tr			35				IC30	C50, IC20
334.4			10	5	40	10	5			30			IC10	IC50	C30, IC10

Mineral Abbreviations

op	orthopyroxene	am	fibrous amphibole	ep	epidote	se	sericite
cp	clinopyroxene	ch	chlorite	cb	carbonate	mg	magnetite
pc	plagioclase	bi	biotite	tc	talc	sl	sulfide
hb	coarse hornblende						

Sample number	% opaques in sample	py	cp	po	pn	vl	ml	sp	ga	Au	vy	ko	me	uA	st	mg	il
P59-520.4	2.0	X	X	X	X							X	X	X		X	X
527.9	3.0	X	X		X											X	X
706.4	tr	X	X							?						X	
P70-278.1	tr	X	X	X	X											X	
331.3	tr	X	X		X											X	
347.4	tr	X	X														
372.0	tr		X							?						X	
P72-118.7	1.0	X	X	X	X												
121.6	2.0		X	X	X											X	
128.5	0.5	X	X	X	X						X						
P75-378.6	tr	X	X		X	X	X									X	
381.4	0.5	X	X		X						X					X	
383.4	0.5	X	X		X						X						
384.2	0.5	X	X		X	X	X					X			X		
399.1	1.0	X	X		X	X	X				X					X	
405.2	1.0	X	X		X		X				X					X	X

Sample number	% opaques in sample	py	cp	po	pn	vl	ml	sp	ga	Au	vy	ko	me	uA	st	mg	il
P75-554.1	15.0	X	X		X			X			X					X	
555.4	8.0	X	X		X				X								
P94-301.3	2.0	X	X	X	X		X										
413.0	20.0	X	X		X											X	X
P96-159.4	1.5	X	X		X		X				X					X	
168.0	tr	X	X		X		X				X						
227.4	5.0	X	X		X		X				X						
P103-106.5	0.5	X	X				X									X	X
P104-434.7	tr	X	X		X					X							
534.6	1.0	X	X		X											X	
588.2	35.0	X	X	X	X											X	X
629.8	2.0	X	X	X	X											X	X
631.7	conc		X	X	X				X							X	X
647.9	2.0	X	X		X			X								X	
668.4	1.0	X	X		X												
680.0	0.5	X	X	X	X												
685.9	conc	X	X	X	X				X		X					X	
712.4	0.5	X	X		X												X

Sample number P104-717.1

% opaques in sample	py	cp	po	pn	vl	ml	sp	ga	Au	vy	ko	me	uA	st	mg	il
conc	X	X	X	X				X	X						X	X

Abbreviations

py	pyrite	Au	gold
cp	chalcopyrite	vy	vyotskite
po	pyrrhotite	ko	kotulskite
pn	pentlandite	me	merenskyite
vl	violarite	uA	unnamed A ($Ag_4Pd_3Te_4$)
ml	millierite	st	stiblopalladinite
sp	sphalerite	mg	magnetite
ga	galena	il	ilmenite

tr	trace amount present	conc	concentrate
----	----------------------	------	-------------

APPENDIX E

ELECTRON MICROPROBE OPERATING CONDITIONS

Pyroxenes and plagioclase were analysed at the Bureau de Recherches Géologiques et Minières, Orléans-la-Source, France. The operators were D.H. Watkinson and C. Gilles.

Sulfides and PGM were analysed by the author, using the Cambridge Instrument Microscan 5 at Carleton University, Ottawa. All analyses were performed at 20 kilovolts with a specimen current of approximately 0.05 microamperes and a counting time of 10 seconds. Sulfides were analysed using minerals of known compositions as standards. The lines and standards used in the analysis of PGM are listed below.

Element	Line	Standard No. and Composition
Pd	L α	310 (Pd _{33.74} Bi _{66.26}), 425 (Pd _{76.84} S _{23.16})
Pt	L α	PLAT (Pt _{100.0}), 426 (Pt _{68.10} Pd _{15.92} S _{15.98})
Te	L α	311 (Pd _{44.34} Te _{55.66})
Bi	M α	310
Ag	L β	133 (Ag _{89.99} Sb _{10.01})
Sb	L α	133
Au	M α	Cu-Au (Au _{81.24} Cu _{18.76})
Fe	K α	FN16 (Fe _{31.02} Ni _{29.95} Co _{1.95} S _{27.10})
Ni	K α	FN16
Co	K α	SAFF (Co _{28.22} As _{71.77})
S	K α	FN16, 425

APPENDIX F

Table 1 - CHEMICAL COMPOSITION OF ORTHOPYROXENES;
 DRILL HOLE P 57, SOUTHERN PART OF LAC DES ISLES COMPLEX, NORTHWESTERN ONTARIO

	1	2	3	4	5	6	7	8	9	10	11
Na ₂ O	.00	.01	.03	.00	.00	.00	.00	.00	.59	.00	.00
SiO ₂	53.29	53.69	53.74	53.21	54.78	54.46	54.76	55.18	53.04	54.35	53.40
FeO	15.47	14.25	15.73	15.57	15.83	16.02	16.00	16.00	14.56	14.68	14.81
K ₂ O	.00	.00	.00	.00	.00	.00	.02	.00	.00	.00	.02
MgO	25.91	26.19	26.47	26.24	26.97	26.78	26.95	26.26	27.29	25.56	28.47
Al ₂ O ₃	1.51	2.09	1.80	1.83	1.83	2.09	1.16	1.55	1.44	1.16	2.01
Cr ₂ O ₃	.00	.00	.23	.00	.00	.00	.03	.00	.00	.00	.01
CaO	2.08	1.60	.55	1.62	1.53	1.05	.80	1.71	1.89	.99	1.19
MnO	.00	.27	.18	.31	.00	.00	.09	.06	.00	.00	.11
TiO ₂	.13	.00	.14	.03	.08	.06	.07	.14	.08	.05	.14
ZnO	.18	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PnO	.35	.13	.28	.29	.10	.30	.26	.25	.19	.33	.15
Total	98.99	96.27	99.23	99.12	101.12	100.76	102.14	101.15	99.10	97.17	98.38
Na	.000	.001	.003	.000	.000	.000	.000	.000	.042	.000	.000
Si	1.952	1.962	1.955	1.945	1.955	1.951	1.954	1.971	1.935	2.005	1.953
Fe	.474	.438	.475	.476	.473	.480	.537	.478	.445	.453	.453
K	.000	.000	.000	.000	.000	.000	.031	.000	.000	.000	.001
Mg	1.417	1.427	1.436	1.430	1.435	1.430	1.433	1.396	1.485	1.406	1.443
Al	.065	.090	.078	.079	.077	.089	.049	.065	.082	.051	.087
Cr	.000	.000	.007	.000	.000	.000	.001	.000	.000	.000	.000
Ca	.082	.063	.023	.064	.059	.040	.031	.086	.074	.039	.047
Mn	.000	.008	.006	.009	.003	.000	.003	.002	.000	.000	.003
Ti	.004	.000	.004	.001	.002	.002	.002	.004	.002	.001	.004
Zn	.005	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Pn	.011	.004	.005	.009	.003	.009	.008	.008	.005	.011	.005
Total for 6 oxygens	4.011	3.962	3.999	4.014	4.004	4.002	4.019	3.962	4.051	3.967	3.998

- 1 - Norite 156.7. Cumulus grain in clinopyroxene 1. table 2, adjacent to plagioclase
 2 - Cumulus grain enclosed by clinopyroxene 2. Centre of grain.
 3 - Centre of cumulus grain enclosed by clinopyroxene 3, plagioclase and amphibole
 4 - Cumulus grain in clinopyroxene.
 5 - Norite 159.4. Cumulus grain in clinopyroxene 4.
 6 - Grain 6.
 7 - Norite 162.4. Intercumulus orthopyroxene
 8 - Centre of 7.
 9 - Norite 190.5. Centre of cumulus orthopyroxene.
 10 - Edge of 9 adjacent to clinopyroxene 7.
 11 - Bronzite gabbro 199. Cumulus grain.

Table 1 - CHEMICAL COMPOSITION OF ORTHOPYROXENES.
 DRILL HOLE P 57, SOUTHERN PART OF LAC DES ILES COMPLEX, NORTHWESTERN ONTARIO
 (CONTINUED)

12	13	14	15	16	17	18	19	20	21	22	23
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
53.17	53.42	53.23	51.51	53.21	54.01	53.11	54.54	54.70	53.97	53.12	53.30
13.31	12.76	16.25	15.33	13.70	14.06	14.16	13.61	12.24	15.70	16.30	14.78
.00	.00	.05	.00	.00	.00	.00	.00	.01	.00	.00	.00
26.34	27.57	24.97	25.46	27.31	27.83	27.88	28.46	27.32	27.10	26.55	26.37
1.88	2.22	1.77	2.24	1.83	2.06	2.10	1.94	1.85	1.94	1.81	1.83
.00	.08	.00	.20	.00	.04	.00	.00	.00	.12	.01	.00
2.64	1.55	1.81	.41	1.88	.71	.74	.78	2.82	.39	.46	.61
.00	.32	.00	.01	.36	.10	.17	.20	.08	.25	.18	.00
.15	.08	.28	.14	.17	.03	.03	.10	.07	.14	.15	.01
.00	.00	.00	.00	.00	.00	.00	.20	.09	.00	.00	.00
.23	.14	.37	.35	.19	.26	.26	.25	.31	.12	.31	.25
97.85	98.58	98.77	95.88	98.48	99.14	98.49	100.09	98.60	98.76	98.74	98.27
.000	.000	.000	.000	.000	.001	.000	.000	.000	.000	.000	.000
1.950	1.838	1.957	1.943	1.950	1.936	1.948	1.981	1.961	1.850	1.949	1.946
.409	.387	.500	.484	.419	.425	.432	.407	.367	.475	.500	.513
.000	.000	.003	.000	.000	.000	.000	.000	.001	.000	.000	.000
1.440	1.507	1.369	1.432	1.487	1.499	1.515	1.518	1.480	1.480	1.452	1.438
.086	.095	.077	.100	.070	.088	.091	.082	.082	.083	.070	.083
.000	.002	.000	.006	.000	.001	.000	.000	.000	.003	.000	.000
.104	.064	.071	.017	.074	.028	.028	.031	.108	.015	.018	.024
.000	.010	.000	.000	.011	.003	.005	.006	.002	.007	.006	.000
.004	.002	.008	.004	.005	.001	.001	.003	.002	.004	.004	.000
.000	.000	.000	.000	.000	.000	.000	.005	.003	.000	.000	.000
.007	.005	.012	.011	.006	.008	.008	.008	.010	.004	.010	.008
4.001	4.010	3.997	3.998	4.015	4.004	4.017	4.007	3.998	4.002	4.011	4.011

- 12 - Gabbro 214.5. Edge of cumulus
 13 - Central part of 12.
 14 - Norite 257.2. Cumulus grain enclosed by clinopyroxene 10.
 15 - Intercumulus to plagioclase.
 16 - Augite norite 258.5. Cumulus orthopyroxene in plagioclase
 17 - Cumulus orthopyroxene in clinopyroxene 11 and 12.
 18 - Border of 17 adjacent to clinopyroxene 11.
 19 - Norite 262.3. Cumulus grain in plagioclase
 20 - Cumulus grain in clinopyroxene 14.
 21 - Norite 270.2. Cumulus orthopyroxene.
 22 - Border against clinopyroxene.
 23 - Centre of cumulus grain 22.

TABLE 2 - CHEMICAL COMPOSITION OF CLINOPYROXENES
 DRILL HOLE P 57, SOUTHERN PART OF LAC DES ILES COMPLEX, NORTHWESTERN ONTARIO

	1	2	3	4	5	6	7	8	9	10
Na ₂ O	.28	.25	.26	.17	.22	.31	.29	.15	.30	.83
SiO ₂	51.74	51.59	52.91	52.60	52.81	51.68	51.80	51.40	51.85	52.24
FeO	5.58	6.84	6.40	5.39	6.23	5.94	6.34	7.85	5.74	6.11
K ₂ O	.00	.00	.00	.00	.00	.00	.01	.00	.00	.00
MgO	14.37	14.34	14.57	14.52	14.27	14.41	14.89	15.50	14.82	14.05
Al ₂ O ₃	2.85	3.34	2.84	2.41	2.85	3.08	2.58	2.87	3.05	1.73
Cr ₂ O ₃	.09	.01	.01	.00	.14	.02	.00	.04	.19	.00
CaO	22.99	22.86	23.88	24.05	22.57	23.25	22.64	19.48	23.38	23.87
MnO	.12	.00	.00	.13	.03	.00	.018	.00	.00	.00
TiO ₂	.26	.28	.26	.23	.59	.37	.57	.28	.22	.23
ZnO	.28	.00	.00	.00	.32	.00	.00	.00	.00	.00
PbO	.08	.17	.05	.07	.13	.00	.03	.10	.04	.07
Total	98.73	99.70	101.18	95.62	100.16	85.09	99.38	97.70	99.64	89.28
Na	.021	.018	.019	.013	.016	.023	.021	.011	.022	.050
Si	1.934	1.916	1.932	1.946	1.943	1.825	1.926	1.937	1.920	1.952
Fe	.174	.212	.196	.167	.192	.185	.197	.248	.178	.191
K	.000	.000	.000	.000	.000	.000	.001	.000	.000	.000
Mg	.001	.001	.001	.002	.002	.002	.002	.001	.001	.001
Al	.127	.147	.123	.105	.124	.135	.113	.128	.133	.076
Cr	.003	.000	.000	.000	.004	.001	.000	.001	.005	.000
Ca	.921	.910	.935	.954	.890	.928	.903	.787	.928	.960
Mn	.004	.000	.000	.004	.001	.000	.006	.000	.000	.000
Ti	.007	.008	.007	.007	.017	.010	.016	.008	.006	.007
Zn	.008	.000	.000	.000	.009	.000	.000	.000	.000	.000
Pb	.003	.005	.002	.002	.004	.000	.001	.003	.001	.003
Total for 6 oxygens	4.003	4.011	4.007	4.000	3.993	4.007	4.011	3.995	4.014	4.032

- 1 - Morite 156.7 - Large intercumulus grain enclosing orthopyroxene and plagioclase Adjacent to orthopyroxene
- 2 - Border against orthopyroxene 2
- 3 - Morite 159.4 - Intercumulus clinopyroxene enclosing orthopyroxene 5 and 6
- 4 - Grain between orthopyroxenes 5 and 6
- 5 - Morite 162.4 - Intercumulus grain
- 6 - Clear edge of 5 against orthopyroxene
- 7 - Morite 190.5 - Small intercumulus clinopyroxene between orthopyroxene and plagioclase
- 8 - Bronzite gabbro 199 - Large intercumulus grain near orthopyroxene 11
- 9 - Gabbro 214.5 - Interior of large grain enclosing orthopyroxene 12
- 10 - Morite 257.2 - Clinopyroxene with chalcopyrite inclusions.

11	12	13	14	15	16
.17	.20	.17	.18	.18	.23
50.86	51.59	52.95	52.06	52.68	51.60
6.30	5.93	5.07	5.40	7.48	6.50
.00	.00	.00	.00	.00	.01
15.76	15.06	15.15	15.27	14.57	14.53
2.58	3.15	3.20	3.22	2.83	3.11
.00	.07	.16	.13	.23	.11
21.59	22.38	22.85	22.09	21.29	22.18
.00	.00	.08	.18	.00	.00
.02	.19	.08	.09	.16	.33
.00	.00	.00	.00	.00	.00
.06	.01	.19	.09	.12	.13
97.38	98.62	99.94	98.75	99.58	98.77
.013	.015	.012	.013	.014	.017
1.925	1.925	1.941	1.934	1.951	1.928
.199	.165	.156	.168	.232	.203
.000	.000	.000	.000	.000	.001
.890	.838	.829	.846	.805	.810
.116	.139	.139	.141	.124	.137
.000	.002	.005	.004	.007	.003
.876	.895	.898	.880	.845	.888
.000	.000	.002	.005	.000	.000
.001	.005	.002	.003	.005	.010
.000	.000	.000	.000	.000	.000
.002	.001	.006	.003	.004	.004
4.022	4.006	3.990	3.997	3.985	4.001

- 11 - Augite norite 259.5 - Adjacent to orthopyroxene 18
 12 - Adjacent to plagioclase
 13 - Norite 262.3 - Intercumulus clinopyroxene
 14 - Centre of 13
 15 - Norite 270.2 - Border against orthopyroxene 22
 16 - Centre of 15.

APPENDIX G
CHEMICAL COMPOSITION OF SULFIDES FROM THE ROBY ZONE

Table G-1 Chemical composition of pyrite in P58-322.1

	Weight Percent				
	1	2	3	4	5
Fe	42.3	42.7	42.8	43.1	42.8
Co	2.03	1.15	1.27	1.00	1.11
Ni	1.28	1.08	0.99	0.97	1.39
S	53.5	53.5	53.5	53.6	54.3
Total	99.11	98.43	98.56	98.67	99.60

Atomic Proportions

Fe	0.76	0.76	0.77	0.77	0.77
Co	0.04	0.02	0.02	0.02	0.02
Ni	0.02	0.02	0.02	0.02	0.02
S	1.67	1.67	1.67	1.67	1.69

(M_{0.98}S_{2.02} - Anal. 2-5; M_{0.99}S_{2.01} - Anal. 1)

Cu, Pd not detected

Table G-3 Chemical composition of violarite in P75-384.2

	1	2	3	4	5	6	7	8	9
Ni	32.0	32.3	32.6	33.1	32.4	32.5	31.8	32.1	31.5
Fe	11.2	11.2	10.1	10.4	11.5	12.5	12.9	10.8	10.0
Co	9.7	9.8	11.4	11.1	10.0	8.9	9.4	10.6	11.9
S	41.4	41.2	40.6	40.0	40.9	41.0	41.3	41.4	41.0
Total	94.3	94.5	94.7	94.6	94.8	94.9	95.4	94.9	94.4

Weight Percent

Atomic Proportions

Ni	0.55	0.55	0.56	0.56	0.55	0.55	0.54	0.55	0.54
Fe	0.20	0.20	0.18	0.19	0.21	0.22	0.23	0.19	0.18
Co	0.17	0.17	0.19	0.19	0.17	0.15	0.16	0.18	0.20
S	1.29	1.29	1.27	1.25	1.28	1.28	1.29	1.29	1.28

(M₂.91S₄.09 - Anal. 1,2,8; M₂.93S₄.07 - Anal 6,7,9; M₂.95S₄.05 - Anal. 5; M₂.96S₄.04 -Anal. 3; M₃.00S₄.00 - Anal. 4)

Pd not detected

Table G-4 Chemical composition of millerite in P75-384.2, P96-227.4

	Weight Percent									
	1	2	3	4	5	6	7	8	9	10
Ni	63.3	63.8	63.6	64.1	64.2	64.0	63.9	64.1	64.0	64.1
Fe	1.3	1.0	1.2	1.2	1.1	1.1	1.4	1.1	1.3	1.3
S	34.6	34.6	34.8	34.8	35.2	34.7	35.1	34.9	34.5	35.0
Total	99.35	99.52	99.73	100.19	100.58	99.88	100.59	100.21	99.86	100.46

1 63.5 64.2
2 1.4 1.3
35.6 35.4

Atomic Proportions

Ni	1.08	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.08
Fe	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02
S	1.08	1.08	1.09	1.08	1.10	1.08	1.10	1.09	1.08	1.11

(M₁.00S₁1.00)(M₁.02S₀.98 - Anal. 1-4, 6-9; M₁.01S₀.99 - Anal. 5, 10)

Co, Pd, Pt not detected

APPENDIX H
CHEMICAL COMPOSITION OF PGM FROM THE ROBY ZONE

Table H-1 Chemical composition of kotulskite in P58-322.1

	1	2	3	4	5	6	7
Pd	40.4	40.2	40.2	40.8	40.4	40.3	39.9
Pt	0.88	1.0	0.74	0.85	0.82	0.79	0.85
Te	39.0	39.4	39.6	39.5	39.6	40.4	41.5
Bi	19.4	19.4	19.4	19.3	19.4	16.0	15.2
Ag	—	—	—	—	—	1.9	1.6
Ni	0.11	0.09	0.24	0.33	0.23	0.05	0.05
Total	99.79	100.09	100.18	100.78	100.45	99.45	99.12
Atomic Proportions							
Pd	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Pt	0.01	0.01	—	—	—	—	—
Te	0.31	0.31	0.31	0.31	0.31	0.31	0.33
Bi	0.09	0.09	0.09	0.09	0.09	0.08	0.07
Ag	—	—	—	—	—	0.02	0.01
Ni	—	—	—	0.01	—	—	—

(Pd_{0.97}Te_{1.03} - Anal. 6,7,8; Pd_{0.98}Te_{1.02} - Anal. 3,5; Pd_{0.99}Te_{1.01} - Anal. 1,2,4)

6 and 7 coexist with merenskyite and unnamed Ag₄Pd₃Te₄

Table H-2 Chemical composition of vysotskite in P96-227.4

	Weight Percent							
	1	2	3	4	5	6	7	8
Pd	66.1	66.7	66.8	65.5	65.3	65.6	67.2	66.7
Pt	0.63	1.6	0.76	1.2	1.4	1.3	2.0	1.9
Fe	2.1	0.51	0.47	0.69	0.85	0.64	0.38	0.15
Ni	11.3	9.5	11.0	10.7	9.4	10.9	9.5	10.1
S	24.3	24.1	24.3	24.4	23.1	24.4	24.1	24.2
Total	104.43	102.41	103.33	102.49	100.05	102.84	103.18	103.05
Atomic Proportions								
Pd	0.62	0.63	0.63	0.62	0.61	0.62	0.63	0.63
Pt	—	0.01	—	0.01	0.01	0.01	0.01	0.01
Fe	0.04	0.01	0.01	0.01	0.02	0.01	0.01	—
Ni	0.19	0.16	0.19	0.19	0.16	0.19	0.16	0.17
S	0.76	0.75	0.76	0.76	0.72	0.76	0.75	0.75

(M₁.04S_{0.96} - Anal. 2-4, 6-8; M₁.05S_{0.95} - Anal. 5; M₁.06S_{0.94} - Anal. 1)

APPENDIX I

EXPLORATION SUGGESTIONS

Information obtained during this study regarding the shape, orientation and mineralogy of the mineralized zone of the western gabbro permits several conclusions to be drawn and exploration suggestions made.

1. The "C-zone" is not a separate zone oriented more easterly than the Roby zone and the layering in the "C-zone" is interpreted to be approximately parallel to that in the Roby zone.

2. Sections drafted for the Roby zone indicate that the mineralized zone plunges shallowly at an azimuth of approximately 160° . Therefore it would be worth drilling a few deeper holes south of the presently known Roby zone.

A deep hole (D-1) drilled by Boston Bay Mines intersected PGE mineralization to a depth of at least 445 metres at section 508. Therefore the possibility exists that considerably more Pd-Pt-Cu-Ni ore is present in the Roby zone than has been outlined to date.

3. The discovery of silver-bearing minerals and gold in sections from the Roby zone means that it would be worth assaying some core for these elements. In addition, since the ratio Pd:Pt is not well documented throughout the Roby zone, some assays to distinguish Pd and Pt would be useful.

4. Map and sample the Shelby Lake, Demars Lake and Wakinoo Lake bodies. It is likely that these three bodies are co-magmatic with the western gabbro of the Lac des Iles complex and before granite emplacement they may have formed a continuous unit with the shape of a sill. A thorough search of these bodies for PGE seems justified.

END

04 · 03 · 80

FIN